NATIONAL URANIUM TAILINGS PROGRAM

Energy, Mines and Resources Canada
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Canada

The Role of Lacustrine Organisms in the Removal of Radionuclides from Surface Waters

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A Report Prepared for:

The National Uranium Tailings Program
Canada Centre for Mineral and Energy Technology
Energy, Mines and Resources Canada
555 Booth Street
Ottawa, Ontario
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Energy, Mines and Resources Canada
National Uranium Tailings Program
Canada Centre for Energy and Mineral Technology
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Attention: Roy D. John, Manager - Measurements

Gentlemen:

Re: The Role of Lacustrine Organisms in the Removal of Radionuclides from Surface Waters
Reference No. 15SQ.23241-4-1698

Monenco Consultants Limited is pleased to present 35 copies of the report entitled "The Role of Lacustrine Organisms in the Removal of Radionuclides from Surface Waters".

The report presents the results of aquatic microcosm studies which determined the short-term (three months) uptake and distribution of radionuclides introduced into the water of pelagic (or limnetic), profundal, and littoral type communities.

The use of a "control" microcosm (without organisms) for each community type permitted observations relating to the effect lacustrine communities have on the removal of radionuclides from water.

The radionuclides used in this study were Radium-226, Lead-210, Thorium-228, Polonium-210 and Uranium because these are all relevant to the potential aquatic impacts of uranium mining and milling.

Yours very truly,

Leslie A. Panek

Leslie A. Panek
Assistant Manager
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EXECUTIVE SUMMARY

Laboratory microcosms designed to contain limnetic, profundal and littoral communities were constructed to determine the effects of these communities on the transfer of radionuclides from the water to the sediment. Each set of experimental microcosms had a corresponding control microcosm which was devoid of organisms.

The limnetic microcosms demonstrated large (i.e. greater than 90%) losses of all radionuclides, except uranium, from the water over the three month period of the experiment. Differences between the control and experimental microcosms were only significantly different for uranium lead-210 and polonium-210. Thus, the presence of a limnetic community (i.e. phytoplankton and zooplankton) did appear to reduce the concentration of these radionuclides in the water. The particulate sedimentary matter and suspended material accounted for the majority of radium-226, lead-210 and polonium-210 activity in the experimental microcosms. Adsorption to the microcosm walls accounted for the majority of activity of thorium-228.

The experimental profundal microcosms demonstrated large (i.e. greater than 74%) losses of all introduced radionuclides from the water. The control microcosm water radionuclides differed significantly from the experimental microcosms water radionuclides in terms of concentration of uranium and the activities of radium-226 and thorium-228. However, the larger suspended material component (i.e. 20 times the average experimental microcosm) in the control microcosm made these differences difficult to interpret. The concentrations or activities of the radionuclides in the control microcosm sediment were not significantly different from the range of concentrations or activities of the experimental microcosms. Mass balances of the radionuclides demonstrated that the surface 4 to 5 cm layer of sediment accounted for the majority of the total radionuclide activity, except for uranium. The water contained the majority of the total uranium in the microcosms.

The experimental littoral microcosms demonstrated large (greater than 88%) losses of all radionuclides from the water with uranium concentrations and radium-226 activities being significantly lower in the experimental microcosms. Thus, the littoral community apparently had an effect on reducing the concentration of uranium and the activity of radium-226 in the water. The decrease in concentration of uranium in the water was accompanied by a significant uranium concentration increase in the surface sediment fraction (0-3 cm) in the experimental microcosms compared to the control microcosm. The activities of the other radionuclides in the various sediment fractions of the control microcosm were not significantly different from the corresponding fractions in the experimental microcosms. Some of the various biological components of the littoral community concentrated the radionuclides to levels several thousand times the initial water concentration or activity. The majority of the total radionuclide activity in the experimental littoral microcosms, except for uranium, was accounted for by the surface sediment fraction (0-3 cm).

A literature review of the dispersion and mixing of sediment-bound radionuclides in actively bioturbated sediment showed that a surface discrete layer of sediment-bound radionuclides is mixed throughout the biologically active sediment layer by the action of vertically oriented, deposit feeding benthic organisms. Uranium, radium-226, thorium-228, lead-210, and polonium-210 could be expected to behave in this fashion if deposited as a discrete layer on an actively bioturbated sediment. Some differences would result from the individual properties of the specific radionuclides. Uranium, being more soluble, would tend to disperse through the active sediment layer (via pore water) faster than the more readily adsorbed radionuclides. There is a potential for radium-226 to be remobilized if the active sediment layer substantially reduces the organic content of the sediment. Polonium-210 apparently has an affinity for freshwater fauna, especially mollusca. Thus, a potential exists for this radiouclide to be bound to the epibenthic fauna (e.g. snails) and not be completely mixed within the active sediment layer.

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PART 1

INTRODUCTION

PART 1 - INTRODUCTION

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1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

The National Uranium Tailings Program (NUTP) has as its mandate the formulation of a predictive mathematical model for the long-term fate of radionuclides introduced into the aquatic environment as the result of uranium mining and milling operations. Radionuclides entering the aquatic environment have the potential to interact with organisms inhabiting the aquatic ecosystem and subsequently be removed from the surface waters. The request for proposal from the National Uranium Tailings Program consisted of the following questions:

- What roles do biological organisms play in the removal of radionuclides from the surface waters?
- What relationship is there between the pelagic, (i.e. limnetic) profundal and littoral zones in this regard? and
- What effects do zoobenthic organisms have on the redistribution of radionuclides within the active sediment layer?

Monenco proposed to conduct an initial survey of the published and unpublished data concerning the roles of limnetic, profundal and littoral organisms on the removal of radionuclides from surface water and their subsequent deposition in the sediment. In addition, the existing information on the redistribution of radionuclides within the sediment would also be examined. If information was lacking about any of these organism-radionuclide interactions, Monenco planned to construct microcosms to try and add information concerning specific lake community types (limnetic, profundal and littoral) and radionuclide sedimentation and redistribution. This proposal was accepted by the NUTP.

1.2 PREVIOUS STUDIES

Monenco reviewed the literature pertaining to the removal of radionuclides associated with uranium mining and milling by lacustrine organisms. Literature concerning the effects of zoobenthic organisms on the mixing and dispersion of radionuclides within the active sediment layer was also examined. Although information existed on the uptake of radionuclides by various aquatic organism known to inhabit lakes, studies demonstrating the removal of radionuclides from surface water by distinct lacustrine communities (i.e. littoral, limnetic, and profundal) were not found.

By contrast, studies using laboratory microcosms specifically designed to monitor the mixing and burial of radionuclide contaminated sediment were abundant. While these studies did not use the radionuclides associated with uranium mining and milling, their sophisticated construction and operation allowed the results derived from them to be applied to any sediment-bound contaminant.

From the literature review, it was apparent that littoral, limnetic, and profundal laboratory microcosms had not been used for examining of the removal of uranium, radium-226, thorium-228, lead-210 and polonium-210 from water. It was also apparent that further laboratory microcosm work to examine mixing and burial of sediment-bound radionuclides was not necessary.

1.3 SCOPE OF WORK

Monenco constructed laboratory microcosms for limnetic, profundal and littoral communities and introduced known amounts of uranium, and know activities of radium-226, thorium-228, lead-210, and

polonium-210 into the microcosms. Uranium, thorium-228, lead-210 and polonium-210 were introduced as nitrates. Radium-226 was introduced as a chloride.

To determine the effect of organisms on the removal of the introduced radionuclides, one microcosm structure (termed the control) within each set of experimental microcosms (i.e. limnetic, profundal, and littoral) was devoid of organisms. For the limnetic microcosms, the control consisted of filtered (0.45 u) lake water. The littoral and profundal controls consisted of sterilized (i.e. autoclaved) sediment and filtered (0.45 u) water.

After the microcosm had been allowed to develop for three months, the microcosms (including the control) were completely disassembled and their component parts (e.g. water, sediment, organisms, suspended material) analyzed for the introduced radionuclides. While it was realized that different organisms within each microcosm might vary dramatically in their ability to remove radionuclides from water, it was never the intent of this study to deal with individual species of either the fauna or flora. Macrophyte growth within each littoral microcosm was combined for a total macrophyte biomass from each of the six experimental microcosms. Similarly, all macroinvertebrate benthic animals in each of the profundal and littoral microcosms were combined to obtain a total biomass for each of the individual microcosms without regard for species separation.

The time frame of three months for the uptake of radionuclides was dictated by the need to conduct the project and produce a report within the time frame specified by the request for proposal. Equilibrium of the radionuclides within the microcosms could not be achieved within this time frame, thus the major emphasis of the study was to examine:

- the transport of the introduced radionuclides out of the water column by a limnetic community;

- o the effect of the presence of a profundal community on the uptake of the introduced radionuclides by profundal sediment; and

- o the effect of the presence of a littoral community on the uptake of the introduced radionuclides by littoral sediment.

In the discussions which follow concerning the concentrations of radionuclides in the components of the various microcosms it was believed necessary to mention the degree to which each microcosm component had concentrated a particular radionuclide. Normally this concentration factor is a ratio of the final concentration of the radionuclide in the water and the particular component in question at equilibrium. However, since many factors (both biological and non-biological) other than the microcosm component in question resulted in the non-equilibrium removal of the radionuclides from the water, concentration factors using the final water concentration were extremely high compared to existing literature values. As an alternative, the initial concentration of radionuclide in the water was used to establish a concentration factor. These factors are only for comparison within the context of the study results and are not meant to be used in any other fashion.

1.4 RADIOCHEMICAL ANALYSIS QUALITY ASSURANCE PROGRAM

Analyses of the microcosm samples were conducted by Monenco Analytical Laboratories. As part of their quality control procedures Monenco Analytical Laboratories uses administrative, statistical, investigative, preventative and corrective techniques to maximize reliability of the data. These techniques include:

- Publication and distribution of current and complete analytical methods and procedures and analytical instrument operating instructions;

- Distribution and retention of laboratory reports with provision for administrative technical review;

- Quality control checks on analytical instruments to ensure their proper functioning at all times;

- A preventative maintenance program;

- A total analytical quality control system to ensure continued precision and accuracy of laboratory results. This includes:

  - Daily calibration (instrument standards);

  - Where available, control samples included with each run. A control sample is one that has a similar matrix and has a working value established by organizations such as ASTM or APHA;

  - When a control sample is not available, a previously run unknown is included as a blind check sample;

  - A reagent blank is analyzed for all parameter determinations;

  - If the results attained for the standards, control or recycle samples are not within acceptable established limits, the entire batch of analyses are repeated and control verified before reports are issued. If sufficient quantities of material are not available for

reanalysis, the client must wave quality control actions if the report of the analysis is to be issued.

- Participation in inter-laboratory quality evaluation programs;

- All personnel are trained and qualified in quality control techniques prior to running new analyses.

In addition, the following quality control operating principles are in effect at Monenco Analytical Laboratories:

- Record Keeping: this program endeavours to establish acceptable quality control records. Each sample is assigned a laboratory number and the analysis parameters requested are tabulated in a log book.

- Reporting Practice: each analysis report is prepared in triplicate. One copy is sent to the client and the other copies are filed in a "correspondence out" file and in the specific project file. All raw data used to calculate each parameter are filed and stored in locations dedicated to that parameter and are retained for a period of two years. This practice allows re-checking of measurement data and calculations as necessary. Where possible, the estimated precision of all data are also included.

- Sample Storage: when available, each sample is retained in storage for a period of two years.

- Instrument Calibration: a detailed plan is available to control the accuracy of measuring by use of calibration standards. Prior to the measurement of a parameter for a batch of samples, the instrument and method is calibrated using appropriate dilutions of certified standard solutions or

sources. each calibration standard is prepared in using a certified written procedure. The calibration procedure and measurement methodology is documented for reference purposes.

- Calibration Interval: each method and instrument is calibrated with solutions prepared using certified calibration standards each time a batch of samples are analyzed. The calibration interval is based on the degree of usage. The laboratory maintains all data and historical records pertaining to the calibration and maintenance of the instrumentation.

- Standards and Tracers: Table 1-1 lists the standard reference materials, their activity and results of analysis using these standards. One to two standards were used per batch of up to twenty (20) samples. Agreement must be obtained prior to reporting of the data. Tracers, where available, are used in all analyses to check recovery. These tracers included Barium-133 for Radium-226/Radium-224, Polonium-208 for Polonium-210, and Thorium-234 for Thorium-232/Thorium-230/Thorium-228.

- Environmental Conditions: all measurements and calibrations are carried out in an area that provides for the control of environmental conditions to the degree necessary to ensure required accuracy. The area is free of dust, vapours and vibration. Each instrument is located away from equipment that produces vibration, chemical emissions or noise. The laboratory area is maintained at a temperature of 21 to 22°C. The analytical balances and electronic equipment for radiochemistry and the ICP-ES unit, for trace elements measurement, are located in an air conditioned environment. A filter air supply is provided to this area.

- Preventative Maintenance: a preventative maintenance program is in effect that includes cleaning, lubricating, adjusting and

TABLE 1-1

Standard Reference Materials

Radionuclide	Reference	Activity	Results[2]
Ra-226	RAY.44[1]	0.99 Bq/ml	0.97 to 1.02 Bq/ml
	UTS-1	3.67 Bq/g	3.60 to 3.80 Bq/g
Th-228	RLZ.44[1]	1.49 Bq/ml	1.40 to 1.55 Bq/ml
	UTS-1	0.71 Bq/g	0.65 to 0.80 Bq/g
Th-230	UTS-1	3.60 Bq/g	3.50 to 3.80 Bq/g
Th-232	UTS-1	0.68 Bq/g	0.60 to 0.80 Bq/g
Pb-210	RBZ.44[1]	3.52 Bq/ml	3.30 to 3.70 Bq/ml
	UTS-1	3.25 Bq/g	3.10 to 3.40 Bq/g
Ra-228	$Th(NO_3)4.4H_2O$[3] in Solution	4.08 Bq/ml	3.75 to 4.25 Bq/ml
	UTS-1	0.68 Bq/g	0.60 to 0.80 Bq/g
Po-210	RBZ.44[1]	3.52 Bq/ml	3.40 to 3.60 Bq/ml
	UTS-1	3.10 Bq/g	3.00 to 3.10 Bq/g

(1) These Standardized Radioactive Solutions were obtained from AMERSHAM CORPORATION. Sources prepared from these solutions are used daily to calibrate counting instruments and as standards.

(2) This column summarizes results obtained in Monenco Lab during 1985.

(3) 1 mg Thorium per ml.

testing of all instruments on a regular basis. Its purpose is to increase measurement system reliability and thus increase data completeness. A preventative maintenance schedule calling for visual and electronic examination of the instrumentation is presently in effect.

- Inter-Laboratory Testing programs: this laboratory participates in inter-laboratory testing programs organized by:

  - Environment Canada
  - Alberta Environment
  - Saskatchewan Environment
  - Western Enviro-Agricultural Laboratories Association
  - U.S. EPA
  - CANMET

  These proficiency testing procedures provide detailed information on how well the laboratory is able to perform.

  Barringer Magenta Laboratories (Alberta) Ltd. conducted some of the uranium analyses for this study and maintains a similar quality control program to that described for Monenco Analytical Laboratories.

PART 2

LIMNETIC MICROCOSMS

PART 2 - LIMNETIC MICROCOSMS

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2.0 LIMNETIC MICROCOSMS

2.1 INTRODUCTION

The limnetic zone is occupied by suspended organic and inorganic material, phytoplankton, zooplankton, and fish. Studies in the scientific literature have demonstrated that radionuclides are both adsorbed and absorbed by planktonic algae (Havlik 1971, Havlik and Robertson 1971, Tanaka et al. 1983). Phytoplankton and unicellular algae in general accumulate more radionuclides per unit weight than any other aquatic organism. Death and subsequent sinking of these planktonic organisms has the potential to remove radionuclides from the water.

Zooplankton are known to remove radionuclides by two mechanisms:

- ingestion of algae containing radionuclides and subsequent incorporation of gut contents into a fecal pellet which transfers to the sediment by sinking (Cherry et al. 1978, Li et al. 1981, Beasley et al. 1978); and
- adsorption of radionuclides onto the exoskeleton which is subsequently moulted and sinks (Fowler 1977, Martin 1970).

The purpose of constructing a series of limnetic microcosms was to ascertain information on the transfer of introduced radionuclides out of the water column in a system containing only zooplankton and phytoplankton. The microcosms were not designed to differentiate between various types of uptake (i.e. adsorption, absorption). Rather, they were designed to demonstrate the total ability of the organisms in the limnetic system to transfer the introduced radionuclides from the water column to the bottom of the enclosure by the sinking of dead algal cells,

dead zooplankters, zooplankton exuviae and fecal pellets. Fish were not included in these microcosms (based on the recommendations of Giddings 1983) because of significant distortions they cause to energy flow and nutrient flows in microcosms compared to the normal ecosystem.

2.2 METHODS AND MATERIALS

The five limnetic microcosms were constructed from 20 cm diameter, schedule 40 PVC pipe. Each 1.5 m section of pipe was sealed at one end with a PVC pipe cap and placed vertically in a wooden frame for support. A 1.3 cm PVC threaded hose connector was placed at the lower end of each pipe section just above the cap for the purpose of draining the water from the pipe. A 1/25 HP stirring motor was mounted on the wood support frame for each of the five microcosms. These stirring motors and attached stirrers were installed at an angle so that cool white fluorescent lights (40 watt) could be suspended directly above the columns.

Collection of the sinking algal cells, exuviae, zooplankton and fecal pellets was accomplished by placing a plastic basket at the bottom of the column. This basket was filled with 97 18 x 150 mm glass test tubes to act as sediment traps. The large number of tubes prevented currents generated by the stirring motor from resuspending sedimentary material once it had entered the tubes.

After four of the five cylinders were filled with untreated lake water (approximately 48 litres), the baskets containing the test tubes (filled with distilled water) were lowered to the bottom of the pipe. The fifth microcosm (the control) was filled with membrane filtered (0.45 u) lake water. Stirrers attached to the rheostat-controlled electric motors created a gentle mixing at approximately 150 revolutions per minute. Distilled water was added periodically to compensate for

losses due to evaporation. Figure 2-1 is a diagram of the limnetic microcosms used in this study.

Owing to the time of the year (March) at which the lake water for these microcosms was collected, very low densities of phytoplankton were contained in the microcosms. A synthetic inorganic algal medium was made up and introduced into the microcosms to promote algal growth. After several weeks, a significant growth of phytoplankton was observed and the following radionuclides were introduced:

- 37 Bq radium-226/litre of water (1800 Bq per microcosm);
- 37 Bq lead-210/litre of water (1800 Bq per microcosm);
- 37 Bq polonium-210/litre of water (1800 Bq per microcosm);
- 25 Bq thorium-228/litre of water (1200 Bq per microcosm);
- 1 mg uranium-238/litre of water (48 mg per microcosm).

Periodically, 250 ml samples of the phytoplankton populations in each column were taken and preserved with Lugols solution for density analysis.

The algal blooms initially induced in the limnetic microcosms rapidly declined and phytoplanktonic algal growth was sporadic thereafter. Although no attached algal growth was observed on the walls of the microcosms at the time the radionuclides were introduced and for many weeks thereafter, attached growth did become heavy by the end of three months. Although not originally considered for sampling, concern over the attached algae's possible involvement in extracting radionuclides from the water prompted the sampling of this microcosm component. Only uranium, radium-226 and lead-210 were analyzed in this component.

The algal cells and other material in the lake water which had settled to the bottom of the limnetic microcosms (termed "particulate sedimentary matter") had the consistency of a gel. This material could not be concentrated by filtration and had to be concentrated by settling

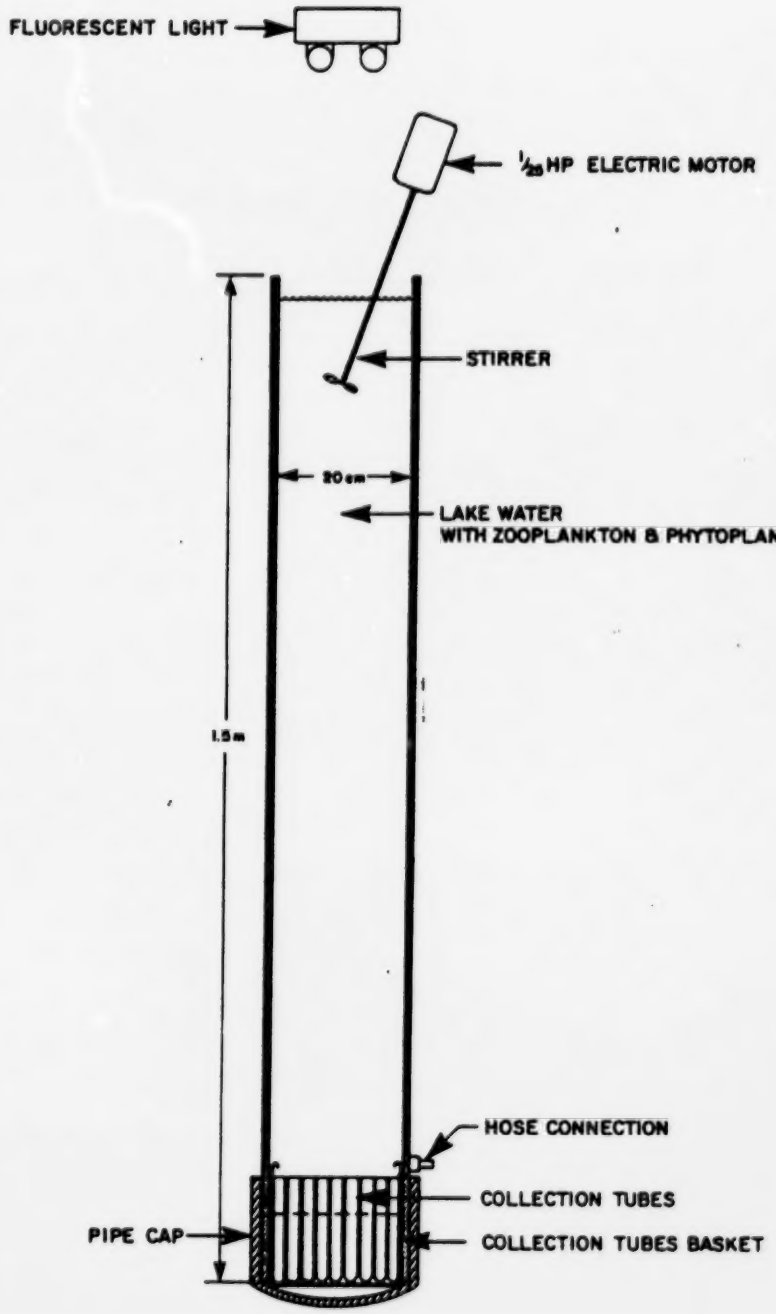

FIGURE 2-1

CROSS-SECTION OF LIMNETIC MICROCOSM

overnight in large glass cylinders. After settling, the supernatant was aspirated off and the jelly-like mass scraped into preweighed plastic weighing boats and dried at 50°C for five days, prior to weighing and analysis.

To compensate for particulate sedimentary matter lost between the glass tubes and the wall of the microcosm, the ratio of the cross-sectional area of the microcosm to the total cross-sectional area of the 97 glass test tubes was multiplied by the particulate sedimentary matter dry weight. This estimate of total particulate sedimentary matter was used for mass balance calculations.

To try and quantify the amount of radionuclide lost due to adsorption an the microcosm walls, the control microcosm was flushed after sampling and filled with tap water. Sulphuric acid was added to reduce the pH to 2.6 and the water was vigorously stirred for 24 hours. This sample (the control microcosm leachate) was collected and analyzed as a water sample.

Suspended material in the four experimental microcosms was sampled by filtering two litres of water through preweighed 0.45 u membrane filters. These filters were dried at 50°C for 24 hours and then desiccated for 24 hours prior to being weighed. Estimates of the total suspended material in each microcosm were derived (i.e. weight of suspended material per litre multiplied by volume of water in microcosm) from these figures.

Attached algal growth on the wall of the microcosms was sampled by scraping the inside wall of each microcosm with a razor blade and washing the residue into a preweighed plastic weighing boat. Approximately 50% of the attached algae was removed in this manner. After drying at 50°C for 24 hours and desiccating for 24 hours the weight of the attached algae was determined. The weights of the attached algae in the microcosm were doubled to account for the 50% of the attached algae

not collected. Thorium-228 and polonium-210 analyses were not conducted on samples of the attached algae so that more analysis of various sediment fractions could be conducted.

2.3 RESULTS AND DISCUSSION

231 INTRODUCTION

Tables 2-1 to 2-4 present the concentrations of radionuclides in the various individual microcosm components (i.e. water, particulate sedimentary matter, suspended material, and attached algae). Also presented are:

- o the average concentrations of radionuclides in each microcosm component for the four experimental microcosms;
- o the concentration of each radionuclide in the control microcosm;
- o the concentration of each radionuclide in the leachate of the control microcosm; and
- o the initial calculated concentrations of radionuclides introduced, in soluble form, to the microcosms.

Table 2-5 presents the weights of various microcosm components used for mass balance calculations.

Tables 2-6 to 2-10 present the mass balances for each radionuclide. Phytoplankton densities in the individual limnetic microcosm sampled at two week intervals are presented in Appendix A.

TABLE 2-1

Radionuclides in the Water of Experimental and Control Limnetic Microcosms

	Total Uranium (ug/L)	Radium-226 (Bq/L)	Thorium-228 (Bq/L)	Lead-210 (Bq/L)	Polonium-210 (Bq/L)
Initial Conc. in Water	1000	37	25	37	37
Microcosm 1	690	5.9±0.20	0.10 ±0.02	3.2±0.2	1.4 ±0.1
Microcosm 2	710	7.1±0.26	0.085±0.017	3.5±0.2	1.4 ±0.1
Microcosm 3	730	7.3±0.30	0.13 ±0.03	3.0±0.2	1.3 ±0.1
Microcosm 4	830	8.7±0.14	0.064±0.019	2.5±0.2	0.85±0.07
Exp. Microcosm Avg.	740	7.23	0.095	3.1	1.2
Control Microcosm	1000	7.9±0.30	0.060±0.01	1.9±0.1	0.34±0.04
Microcosm Leachate	210	18±0.6	7.9±0.4	10.6±0.4	5.1 ±0.1

1. ± variations reflect the statistical precision of counting using the activity of a tracer and the activity of the radionuclide being analyzed.

2. Values are the result of single sample analyses.

TABLE 2-2

Radionuclides Associated with the Particulate
Sedimentary Matter of Experimental Limnetic Microcosms

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Thorium-228 (Bq/g)	Lead-210 (Bq/g)	Polonium-210 (Bq/g)
Initial Conc. in Water	1.0	0.037	0.025	0.037	0.037
Microcosm 1	18	390±15	78±3.1	450±2	230±3
Microcosm 2	8.9	350±12	92±4.2	450±2	220±4
Microcosm 3	7.1	430±20	89±4.4	350±2	240±4
Microcosm 4	8.0	440±36	110±4	320±2	240±4
Exp. Microcosm Avg.	10	400	92	390	230
Relative Concentration Factors	10X	11,000X	3,600X	11,000X	6,300X

1. ± variations reflect the statistical precision of counting using the activity of a tracer and the activity of the radionuclide being analyzed.

2. Values are the result of single sample analyses.

TABLE 2-3

Radionuclides Associated with Suspended Material
from Limnetic Microcosms

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Thorium-228 (Bq/g)	Lead-210 (Bq/g)	Polonium-210 (Bq/g)
Initial Conc. in Water	1.0	0.037	0.025	0.037	0.037
Microcosm 1	2500	240±23	220±12	330±23	300±23
Microcosm 2	1800	150±13	120±9	230±13	310±26
Microcosm 3	1600	170±9	150±9	370±19	280±9
Microcosm 4	1800	160±11	140±11	370±17	270±11
Exp. Microcosm Avg.	1900	180	160	330	290
Relative Concentration Factors	1900X	5,000X	6,000X	8,800X	8,000X

1. ± variations reflect the statistical precision of counting using the activity of a tracer and the activity of the radionuclide being analyzed.

2. Values are the result of single sample analyses.

TABLE 2-4

Radionuclides Associated with Attached Algal Growth
on Limnetic Microcosm Walls

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Lead-210 (Bq/g)
Initial Conc. in Water	1.0	0.037	0.037
Microcosm 1	1.5	200±7	81±4
Microcosm 2	1.3	210±9	96±2
Microcosm 3	1.2	130±5	97±2
Microcosm 4	0.6	170±13	100±3
Exp. Microcosm Avg.	1.2	180	90
Relative Concentration Factors	1X	4,800X	2,500X

1. ± variations reflect the statistical precision of counting using the activity of a tracer and the activity of the radionuclide being analyzed.

2. Values are the result of single sample analyses.

3. Thorium-288 and Polonium-210 were not analyzed for this component.

TABLE 2-5

Components of Limnetic Microcosms
Used for Mass Balances

	Particulate Sedimentary Matter as Dry Weight (g)	Estimated Total Suspended Material as Dry Weight (g)	Estimated Total Attached Algal Growth on Microcosm Walls as Dry Weight (g)
Microcosm 1	3.7363	0.2064	1.1054
Microcosm 2	2.7554	0.1872	2.3710
Microcosm 3	2.5808	0.5184	2.6036
Microcosm 4	3.2678	0.4176	1.5700
Exp. Microcosm Avg.	3.0851	0.3324	1.9125

TABLE 2-6

Uranium Mass Balances for Limnetic Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms				
			1	2	3	4	Mean
Water	48,000 ug (1000 ug/L)	48,000 ug (1000 ug/L)	33,000 ug (690 ug/L)	34,000 ug (710 ug/L)	35,000 ug (730 ug/L)	40,000 ug (830 us/L))	36,000 ug (740 ug/L)
Particulate Sedimentary Matter			66 ug (18 ug/g)	25 ug (8.9 ug/g)	18 ug (7.1 ug/g)	26 ug (8.0 ug/g)	34 ug (10 ug/g)
Suspended Material			520 ug (2500 ug/g)	340 ug (1800 ug/g)	820 ug (1600 ug/g)	750 ug (1800 ug/g)	600 ug (1900 ug/g)
Attached Algal Growth			1.7 ug (1.5 ug/g)	3.0 ug (1.3 ug/g)	3.0 ug (1.2 ug/g)	1.00 ug (0.64 ug/g)	2.2 ug (1.2 ug/g)
Leachate		10,000 ug (210 ug/L)	10,000 ug	10,000 ug	10,000 ug	10,000 ug	10,000 ug
Total		58,000 ug	44,000 ug	44,000 ug	46,000 ug	51,000 ug	46,000 ug

XXX = Total amount in microcosm component
(XXX) = Concentration in microcosm component

TABLE 2-7

Radium-226 Mass Balances for Limnetic Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms				
			1	2	3	4	Mean
Water	1800 Bq (37 Bq/L)	380 Bq (7.9 Bq/L)	280 Bq (5.9 Bq/L)	340 Bq (7.1 Bq/L)	350 Bq (7.3 Bq/L)	420 Bq (8.7 Bq/L)	350 Bq (7.3 Bq/L)
Particulate Sedimentary Matter			1500 Bq (390 Bq/g)	960 Bq (350 Bq/g)	1100 Bq (430 Bq/g)	1400 Bq (440 Bq/g)	1,200 Bq (400 Bq/g)
Suspended Material			49 Bq (240 Bq/g)	29 Bq (150 Bq/g)	89 Bq (170 Bq/g)	67 Bq (160 Bq/g)	59 Bq (180 Bq/g)
Attached Algal Growth			220 Bq (200 Bq/g)	500 Bq (210 Bq/g)	340 Bq (130 Bq/g)	270 Bq (170 Bq/g)	328 Bq (180 Bq/g)
Leachate		860 Bq (18 Bq/L)	860 Bq	860 Bq	860 Bq	860 Bq	860 Bq
Total		1200 Bq	2900 Bq	2700 Bq	2700 Bq	3000 Bq	2800 Bq

XXX = Total amount in microcosm component
(XXX) = Activity per unit of microcosm component

TABLE 2-8

Thorium-228 Mass Balances for Limnetic Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms				
			1	2	3	4	Mean
Water	1200 Bq (25 Bq/L)	2.9 Bq (0.060 Bq/L)	4.8 Bq (0.10 Bq/L)	4.1 Bq (0.085 Bq/L)	6.2 Bq (0.13 Bq/L)	3.1 Bq (0.064 Bq/L)	4.6 Bq (0.095 Bq/L)
Particulate Sedimentary Matter			290 Bq (78 Bq/g)	250 Bq (92 Bq/g)	230 Bq (89 Bq/g)	360 Bq (110 Bq/g)	280 Bq (92 Bq/g)
Suspended Material			45 Bq (220 Bq/g)	22 Bq (120 Bq/g)	78 Bq (150 Bq/g)	58 Bq (140 Bq/g)	51 Bq (160 Bq/g)
Attached Algal Growth			No Analysis	No Analysis	No Analysis	No Analysis	No Analysis
Leachate		380 Bq (7.9 Bq/L)	380 Bq	380 Bq	380 Bq	380 Bq	380 Bq
Total		380 Bq	720 Bq	660 Bq	690 Bq	800 Bq	720 Bq

XXX = Total amount in microcosm component
(XXX) = Activity per unit of microcosm component

TABLE 2-9

Lead-210 Mass Balances for Limnetic Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms				
			1	2	3	4	Mean
Water	1800 Bq (37 Bq/L)	91 Bq (1.9 Bq/L)	150 Bq (3.2 Bq/L)	170 Bq (3.5 Bq/L)	140 Bq (3.0 Bq/L)	120 Bq (2.5 Bq/L)	140 Bq (3.1 Bq/L)
Particulate Sedimentary Matter			1700 Bq (450 Bq/g)	1200 Bq (450 Bq/g)	900 Bq (350 Bq/g)	1000 Bq (320 Bq/g)	1200 Bq (390 Bq/g)
Suspended Material			68 Bq (330 Bq/g)	43 Bq (230 Bq/g)	190 Bq (370 Bq/g)	150 Bq (370 Bq/g)	110 Bq (330 Bq/g)
Attached Algal Growth			90 Bq (81 Bq/g)	230 Bq (96 Bq/g)	250 Bq (97 Bq/g)	160 Bq (100 Bq/g)	180 Bq (94 Bq/g)
Leachate		510 Bq (10.6 Bq/L)	510 Bq	510 Bq	510 Bq	510 Bq	510 Bq
Total		600 Bq	2500 Bq	2200 Bq	2000 Bq	1900 Bq	2100 Bq

XXX = Total amount in microcosm component
(XXX) = Activity per unit of microcosm component

TABLE 2-10

Polonium-210 Mass Balances for Limnetic Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms				
			1	2	3	4	Mean
Water	1800 Bq (37 Bq/L)	16 Bq (0.34 Bq/L)	67 Bq (1.4 Bq/L)	67 Bq (1.4 Bq/L)	62 Bq (1.3 Bq/L)	41 Bq (0.85 Bq/L)	59 Bq (1.2 Bq/L)
Particulate Sedimentary Matter			860 Bq (230 Bq/g)	600 Bq (220 Bq/g)	620 Bq (240 Bq3g)	780 Bq (240 Bq/g)	720 Bq (230 Bq/g)
Suspended Material			62 Bq (300 Bq/g)	58 Bq (310 Bq/g)	150 Bq (280 Bq/g)	110 Bq (270 Bq/g)	95 Bq (290 Bq/g)
Attached Algal Growth			No Analysis	No Analysis	No Analysis	No Analysis	No Analysis
Leachate		250 Bq (5.1 Bq/L)	250 Bq	250 Bq	250 Bq	250 Bq	250 Bq
Total		270 Bq	1200 Bq	980 Bq	1100 Bq	1200 Bq	1100 Bq

XXX = Total amount in microcosm component
(XXX) = Concentration in microcosm component

Student's t-test (using a 0.05 level of significance) was used to determine if the control water radionuclide concentrations were significantly different from the range of radionuclide concentrations found in the water of the experimental microcosms after three months of algal growth and sedimentation (Table 2-1).

232 MASS BALANCES

The mass balances for the limnetic microcosms were good for uranium (an average 96% recovery in the experimental microcosms) and lead-210 (an average 17% overestimation of the activity initially added). The average activity of radium-226 recovered from the microcosm experimental components was 2,800 Bq, or 56% in excess of the activity initially added. On average, only 61% and 60% of the polonium-210 and thorium-228, respectively, were recovered from the limnetic experimental microcosms.

Despite these limitations, the limnetic microcosms demonstrated:

- the bioconcentration of radionuclides by plankton;
- the removal of uranium from water by the sedimentary particulate matter;
- the concentration of radionuclides by sedimentary particulate matter;
- a possible relationship between the weight of suspended material and the activities of radium-226, thorium-228, lead-210, and polonium-210; and
- the uptake of radionuclides by attached algae.

Results of the radionuclide distributions in the limnetic microcosms will be discussed for individual radionuclide in the following sections.

233 URANIUM

.1 Water

Uranium was significantly lower (at the 0.05 level) in the experimental microcosms (range 690-830 ug/L) than in the control microcosm (1,000 ug/L), as determined by Student's t-test.

.2 Particulate Sedimentary Matter

The concentration of uranium in the particulate sedimentary matter which collected at the bottom of the limnetic microcosms ranged from 7.1 to 18 ug/g and averaged 10 ug/g. On average, uranium was ten times more concentrated in this component than the initial water concentration.

.3 Suspended Material

The concentration of uranium associated with the suspended material ranged from 1,600 to 2,500 ug/g and averaged 1,900 ug/g. On average, the suspended material had 1,900 times the activity of the initial water concentration.

.4 Attached Algae

The concentrations of uranium associated with the attached algal growth ranged from 0.64 to 1.5 ug/g and averaged 1.2 ug/g. On average, the concentration of uranium associated with this component was about the same as the initial water concentration.

.5 Distribution of Uranium in Microcosms

Relative to the concentration introduced (i.e. 1,000 ug/L) a large portion of the uranium stayed in the experimental microcosm water and accounted for an average of 75% of the total microcosm uranium (Table 2-6). Among the other components, uranium's highest concentration was associated with the suspended material (average 1,900 ug/g). However, the small weight of this component (0.332 g) allowed it to account for only 1.4% of the microcosm uranium. The particulate sedimentary matter (average 10 ug/g) accounted for less than 1% and the attached algal growth less than 0.01% of the total microcosm uranium.

The control microcosm had the same concentration in the water at the end of the experimental period (1,000 ug/L) as that initially present. The high leachate concentration (210 ug/L) might have been due to inadequate flushing of the control microcosm prior to leaching. If the leachate of the control microcosm is used in the summation of experimental microcosm components, it accounts for 22% of the total.

234 RADIUM-226

.1 Water

The activity of radium-226 in the control microcosm (7.9 Bq/L) was not significantly different from the range of activities exhibited by the experimental microcosms (5.9 to 8.7 Bq/L).

.2 Particulate Sedimentary Matter

The activity of radium-226 in the particulate sedimentary matter ranged from 350 to 440 Bq/g and averaged 400 Bq/g. This component had 11,000 times the initial water activity.

.3 Suspended Material

The activities of radium-226 associated with the suspended material ranged from 150 to 240 Bq/g and averaged 180 Bq/g. On average, the suspended material had 5,000 times the initial water activity.

.4 Attached Algae

The activities of radium-226 associated with the attached algal growth ranged from 130 to 210 Bq/g and averaged 180 Bq/g. On average, the activity of radium-226 associated with this component was 4,800 times the initial water activity.

.5 Distribution of Radium-226 in Microcosms

Radium-226 was lost from the water to a final mean concentration of 7.2 Bq/L or 13% of the total of microcosm components (Table 2-7). The highest activity of radium-226 occurred in the particulate sedimentary matter (400 Bq/g) and its comparatively large mass of this component (3.0851 g) allowed it to account for 43% of the total microcosm radium-226 activity. The attached algal growth also accumulated radium-226 to a mean activity of 180 Bq/g but accounted for only 12% of the total microcosm radium-226 activity. Suspended material accounted for approximately 2%.

The control microcosm water (7.9 Bq/L) had approximately the same activity as the experimental microcosm average but accounted for 32% of the control microcosm radium-226 activity. The control leachate (18 Bq/L) accounted for 72% of the total radium-226 activity. If this is an indication of the activity lost to microcosm walls in the experimental microcosms, then it accounted for 31% of the average radium-226 activity in these microcosms.

235 THORIUM-228

.1 Water

The activity of thorium-228 in the control microcosm (0.060 Bq/L) was not significantly different from the range of activities exhibited by the experimental microcosms (0.064 - 0.13 Bq/L).

.2 Particulate Sedimentary Matter

The activity of thorium-228 in the particulate sedimentary matter ranged from 78 to 110 Bq/g and averaged 92 Bq/g. On average, this component had 3,600 times the initial water activity.

.3 Suspended Material

The activities of thorium-228 associated with the suspended material ranged from 120 to 220 Bq/g and averaged 160 Bq/g. On average, the activity of thorium-228 was 6,000 times the initial water activity.

.4 Attached Algae

The attached algal component was not analyzed for thorium-228 in order that more analytical effort could be devoted to the littoral microcosms.

.5 Distribution of Thorium-228 in Microcosms

At the end of three months, thorium-228 activity in the experimental microcosm water had decreased to an average of 0.095 Bq/L (Table 2-8). This component accounted for less than 1% of the total microcosm thorium-228 activity. The majority of the thorium-228 activity was apparently lost to the walls of the microcosms. Use of the control leachate (7.9 Bq/L) to estimate this component for the experimental

microcosms demonstrated that at least 53% of the thorium-228 activity might have been lost in this manner. Within the microcosms' biological components, the particulate sedimentary matter (92 Bq/g) accounted for 39% of the total thorium-228 activity. The suspended material (160 Bq/g) accounted for 7% of the microcosm thorium-228 activity.

The loss of thorium-228 activity to the microcosm wall is demonstrated by the control microcosm where over 99% of that microcosms recovered activity was present in the leachate. The water in the control microcosm accounted for about the same percentage (0.7%) of the thorium-228 activity as it did in the average experimental microcosm.

236 LEAD-210

.1 Water

The activity of lead-210 in the control microcosm (1.9 Bg/L) was lower than the range of activities in the experimental microcosms (2.5 - 3.5 Bq/L), but this difference was not statistically significant at the 0.05 level. When tested at the 0.1 level, the control was different from the experimental microcosms.

.2 Particulate Sedimentary Matter

The activity of lead-210 in the particulate sedimentary matter ranged from 320 to 450 Bq/g and averaged 390 Bq/g. On average, this component had 11,000 times the initial water activity.

.3 Suspended Material

The activities of lead-210 associated with the suspended material ranged from 230 to 370 Bq/g and averaged 330 Bq/g. On average, the activity of lead-210 was 8,800 times the initial water activity.

There was a relationship between the weight of suspended material and the activity associated with it. Linear regression analysis of the two variables demonstrated a regression coefficient of 0.794 with the relationship defined by:

$$Y = 7{,}711.394X - 217.447$$

where Y is the activity of lead-210 associated with the grams dry weight of suspended material (X).

.4 Attached Algae

The activities of lead-210 associated with the attached algal growth ranged from 81 to 100 Bq/g and averaged 94 Bq/g. On average, the activity of lead-210 was about 2,500 times the initial water activity.

.5 Distribution of Lead-210 in Microcosms

At the end of three months the lead-210 activity had decreased to an average of 3.1 Bq/L (from 37 Bq/L) and accounted for only 7% of the total microcosm lead-210 activity (Table 2-9). The suspended material and particulate sedimentary matter had the highest activities of lead-210 in the microcosm (330 and 390 Bq/g, respectively). Because the particulate sedimentary component had ten times the weight of the suspended material, the former accounted for 57% of the total microcosm lead-210 activity. The suspended material accounted for 5%. The attached algal growth accumulated only about one third of the activity of the suspended material and accounted for 9% of the total microcosm lead-210 activity.

The two components making up the control microcosm (water and leachate) accounted for 15% and 85%, respectively, of that microcosms lead-210 activity. If this leachate is indicative of the magnitude of the activity lost to the walls of the experimental microcosms, it would

have accounted for 24% of the average experimental microcosm total lead-210 activity.

237 POLONIUM-210

.1 Water

The activity of polonium-210 in the control microcosm (0.34 Bq/L) was lower than the range of activities in the experimental microcosms (0.85 - 1.4 Bq/L), but this difference was not statistically significant at the 0.05 level. However, when tested at the 0.1 level, the difference was significant.

.2 Particulate Sedimentary Matter

The activity of polonium-210 associated with this component ranged from 220 to 240 Bq/g and averaged 230 Bq/g. On average, the particulate sedimentary matter had 6,300 times the initial water activity.

.3 Suspended Material

The activities of polonium-210 associated with the suspended material ranged from 270 to 310 Bq/g and averaged 290 Bq/g. On average, the activity of polonium-210 associated with the suspended material was 8,000 times the initial water activity.

.4 Attached Algae

The attached algal component was not analyzed for polonium-210 so that more effort could be directed toward increased sediment analyses in the littoral microcosms.

.5 Distribution of Polonium-210 in Microcosms

After three months, the activity of polonium-210 in the water had decreased to an average of 1.2 Bq/L (from 37 Bq/L) (Table 2-10). This accounted for 5% of the total microcosm polonium-210 activity. The component with the highest activity of polonium-210 was the suspended material (290 Bq/g). Because of its relatively small weight, this component accounted for only 9% of the total microcosm polonium-210 activity. The particulate sedimentary matter was associated with the second highest activity of this radionuclide (230 Bq/g). The relatively large weight of this component resulted in the particulate sedimentary matter accounting for 65% of the total microcosm polonium-210 activity. The attached algal component was not analyzed for polonium-210, but it is doubtful that it could have accounted for the difference between the sum of the microcosm components (1100 Bq) and the initial activity (1800 Bq).

The polonium-210 activity recovered in the control was 15% of the initial activity, probably due to under-estimating the activity loss to the microcosm walls. Of the polonium-210 activity recovered in the control microcosm, 92% was accounted for in the leachate. Like the water in the experimental microcosms, this control microcosm component accounted for 6% of the polonium-210 activity. If the control leachate is used to estimate the activity lost to the experimental microcosm walls, it accounts for almost one quarter of the recovered polonium-210 activity in those microcosms.

238 COMPARISON OF RADIONUCLIDES

The five radionuclides introduced into the water of the limnetic microcosms were reduced in concentration or activity by various factors within the microcosm. These factors were:

- uptake (adsorption or absorption) by the planktonic community and subsequent removal by sedimentation;
- adsorption to suspended material;
- adsorption by the attached algal growth; and
- adsorption to microcosm walls.

The summation of these factors resulted in the removal from the water of the following percentages (relative to the initial amount or activity) of the radionuclides in the experimental microcosms:

- Uranium: 26.0%;
- Radium-226: 91.2%;
- Thorium-228: 99.7%;
- Lead-210: 91.6%; and
- Polonium 210: 96.8%.

Uranium remained in the water to a greater extent than any other of the five radionuclides.

The particulate sedimentary matter resulting from the growth and death of the members of the planktonic community apparently had a significant effect in reducing the amount of uranium in the water of the experimental microcosms. The water activities of lead-210 and polonium-210 were also lower in the experimental microcosms compared to the control but these differences were only significant at the 0.1 level.

Had the microcosms been allowed to continue for a longer time period, the water activities of lead-210 and polonium-210 might also have become significantly different from the control at the 0.05 level.

The particulate sedimentary matter varied in its ability to concentrate (by adsorption or absorption) the radionuclides dissolved in the water. Relative to the initial concentrations added to the water, this microcosm component concentrated the radionuclides by the following factors:

- o Uranium: 10X;
- o Radium-226: 11,000X;
- o Thorium-228: 3,600X;
- o Lead-210: 11,000X; and
- o Polonium 210: 6,300X.

The relationship observed between suspended material and lead-210 is proportional (i.e. increases in one component are accompanied by increases in the other component). The suspended material exhibited radionuclides in excess of the initial water concentrations and activities by the following factors:

- o Uranium: 1,900X;
- o Radium-226: 5,000X;
- o Thorium-228: 6,000X;
- o Lead-210: 8,800X; and
- o Polonium 210: 8,000X.

These relative concentration factors are, with the exception of uranium and polonium-210, all lower than the particulate sedimentary matter relative concentration factors.

Relative to the initial water concentration or activity, the attached algal growth had the following relative concentrations factors;

- o Uranium: 1X;
- o Radium-226: 4,800X;
- o Lead-210: 2,500X;

- o Thorium-228: No analysis; and
- o Polonium 210: No analysis.

Of all the components analyzed in the experimental limnetic microcosms, radium-226, lead-210, and polonium-210 reached their highest activities in either the particulate sedimentary matter or the suspended material. Radium-226 is known to be activity taken up (both adsorption and absorption) by planktonic algal cells, and this could be the reason for the high activity in these components.

The highest uranium concentration in the limnetic microcosms was associated with the suspended material. The exact reason for this association is not clear, but is probably related to the availability of uranium in the water (i.e. its increased solubility as compared to the other radionuclides), the active uptake (absorption) by living algal cells, and its release by dead and senescent cells.

Lead-210 activities were positively correlated with the dry weight of suspended material. This relationship tends to support the hypothesis that surface adsoprtion is one of the major factors in the removal of these radionuclides from water (i.e. the greater the dry weight, the larger the surface area available for adsorption).

Figure 2-2 is a graphic representation of the distribution of radionuclides in the control and experimental limnetic microcosms.

239 SUMMARY OF FINDINGS

The results of the limnetic microcosm experiments can be summarized as follows:

- o Uranium concentrations in water were significantly different (at the 0.05 level) between the experimental microcosms (con-

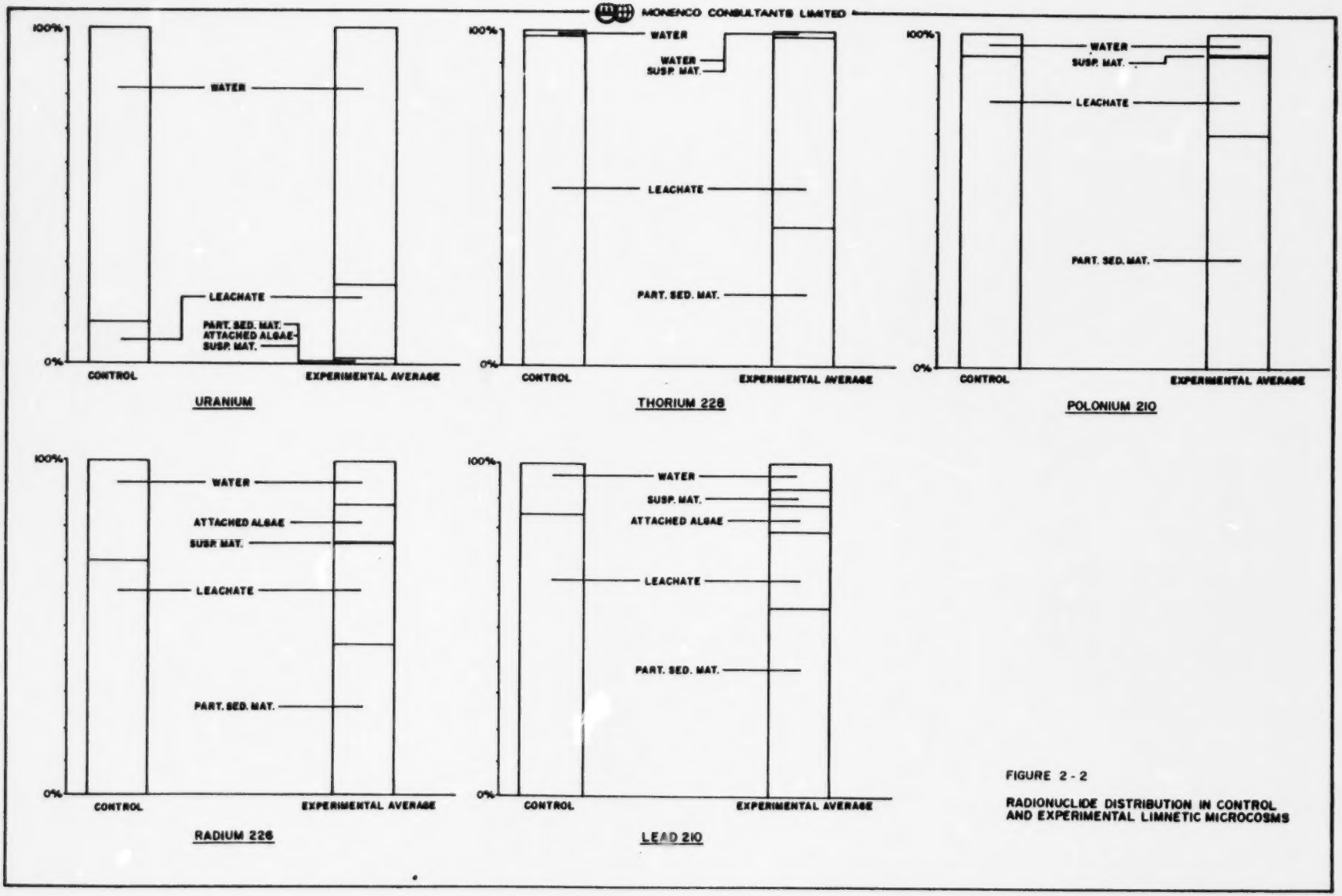

FIGURE 2 - 2

RADIONUCLIDE DISTRIBUTION IN CONTROL AND EXPERIMENTAL LIMNETIC MICROCOSMS

taining a planktonic community) and the control microcosm (devoid of planktonic organisms);

- The amount of uranium in the water of the experimental microcosms was reduced, on average, by 26% relative to the amount added;

- Lead-210 and polonium-210 activities in the water were observed to be lower in the experimental microcosms than in the control, and this difference was statistically significant at the 0.1 level;

- The activities of radium-226, thorium-228, lead-210, and polonium-210 in the water of the experimental microcosms were all reduced, on average, by over 90%, relative to the activities added; and

- The particulate sedimentary matter and suspended material had activities of radium-226, thorium-228, lead-210 and polonium-210 which were several thousand times the initial water activity.

The apparent inconsistency of significant uranium, lead-210 and polonium-210 reductions in the water and non-significant reductions for the remaining radionuclides suggests that factors other than the removal of radionuclides by particulate sedimentary matter were operating in both the experimental and control microcosms. Chief among these factors would have been adsorption to the microcosm walls. If the leachate from the control microcosm was an indication of the activity lost in this manner, then the following percentages of activities recovered in the experimental microcosms can be attributed to this factor:

- Radium-226: 31%; and
- Thorium-228: 57%.

PART 3

PROFUNDAL MICROCOSMS

PART 3 - PROFUNDAL MICROCOSMS

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3.0 PROFUNDAL MICROCOSMS

3.1 INTRODUCTION

The profundal zone is the bottom, deep water area of a lake beyond effective light penetration. Biological production in this zone is the result of input of organic matter from higher in the water column. Little is known regarding the effect of the benthic and epibenthic inhabitants of this zone on the removal of radionuclides from the water.

The purpose of constructing a series of profundal microcosms was to simulate an aquatic environment devoid of plankton, but which contained sediment with a well-developed benthic profundal community. To assess the effect of the organisms on radionuclide removal from the water, the control microcosm was devoid of all life (i.e. sterile sediment and filtered water). Any differences between the dispersal of radionuclides among the components common to all microcosms (i.e. water and sediment) could then be attributed to the presence of the profundal community.

3.2 METHODS AND MATERIALS

The profundal microcosms were constructed from one-metre lengths of 20 cm diameter, one metre long, schedule 40 PVC pipe. Each metre section of pipe was sealed at the bottom with a PVC cap and placed vertically in a wooden frame for support. A 1.3 cm PVC threaded hose connector was placed at the lower end of the pipe just above the pipe cap for the purpose of draining the water from the pipe. With the hose connector at this height, approximately 15 cm was left at the bottom of the pipe for sediment.

A primary concern in this type of microcosm is the occurrence of anaerobic conditions at the sediment-water interface, especially when highly organic sediments are used. To circumvent this potential problem, the shaft of a stirring motor (1/25 HP) was connected to a small piece of wire and submerged below the surface to mix the upper few centimeters of water. This mixing did not break the surface of the water nor did it disturb the sediment at the bottom of the pipe. It did allow the maintenance of oxygen saturation conditions throughout the water column as confirmed by dissolved oxygen probe measurements.

The sediment used for the microcosms was collected from a local lake (Chestermere Lake), homogenized in a large plastic tubs and placed in the bottom of the vertical pipe sections. Exactly 500 ml of the homogenized sediment was weighed for a determination of density (1.43 g/ml). This sediment was then dried at 50°C for one week and the density of the dry sediment determined (12.57 g/ml). From these measurements, it was estimated that the top layer of sediment, from which the sediment cores were taken at the end of the experimental period, was approximately one kilogram (dry weight). Filtered (0.45 u) lake water (approximately 27 litres) was added and the sediment allowed to settle for three days prior to starting the stirring motors. Several attempts were made to reduce the amount of suspended material in the water prior to radionuclide introduction, but microcosms 2 and 4 (the control) remained turbid. Although some benthic organisms were observed during the homogenization process, additional chironomid larvae and oligochaetes were introduced to increase the populations in each of the three microcosms containing organisms.

Sterile sediment for the control microcosm was provided by first drying and then autoclaving a portion of the homogenized sediment for two hours at 138 kPa and 150°C.

Figure 3-2 is a diagram of the profundal microcosms used in this study.

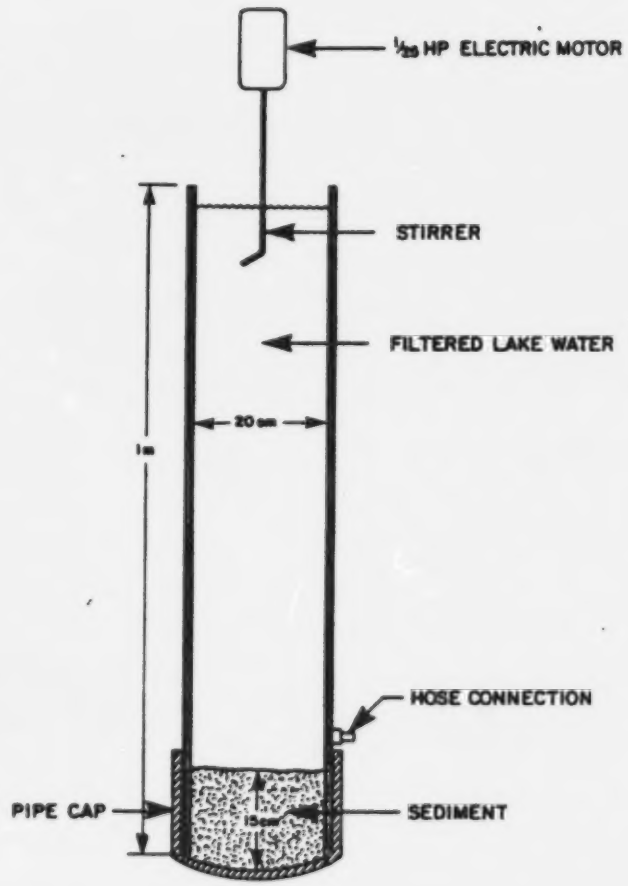

FIGURE 3-2

CROSS-SECTION OF PROFUNDAL MICROCOSM

After conditions had stabilized in all microcosms, the following activities and quantities of radionuclides were introduced:

- 44 Bq radium-226/litre of water (1200 Bq per microcosm);
- 44 Bq lead-210/litre of water (1200 Bq per microcosm);
- 44 Bq polonium-210/litre of water (1200 Bq per microcosm);
- 35 Bq thorium-228/litre of water (950 Bq per microcosm);
- 1.2 mg uranium-238/litre of water (32 mg per microcosm);

Distilled water was added periodically to compensate for losses due to evaporation.

At the end of the three-month experimental period, suspended material from each microcosm was collected by filtering two litre water samples through pre-weighed 0.45 u filters. The filters were dried for 24 hours at 50°C and reweighed for a determination of suspended material weight. This weight was used to determine the total amount of suspended material in each microcosm.

Three sediment samples were taken from each microcosm by pushing a 2.5 cm ID plastic tube into the sediment to the bottom of the microcosm. Only the top four to five centimetres of sediment were retained in the plastic tube. These sediment cores were combined for analysis of radionuclide content.

After removal of the sediment cores, the remainder of the sediment from each microcosm was placed in a large plastic tub. Subsequently, the sediment from each microcosm was washed (elutriated) to remove the fine silt. The contents of the elutriator (which used a 0.5 mm mesh plastic screen) was then placed in a white porcelain pan and organisms were removed with forcepts and placed in pre-weighted plastic dishes. Faunal samples were dried at 50°C for three days and their dry weights determined.

3.3 RESULTS AND DISCUSSION

331 INTRODUCTION

Tables 3-1 to 3-4 present the concentrations of radionuclides in the various individual microcosm components. (i.e. water, sediment, suspended material, and fauna). Also presented in each table are:

- the average concentrations and activities of radionuclides in each microcosm component for the three experimental microcosms;
- the concentration and activities of radionuclides in the control microcosm; and
- the initial calculated concentration and activities of radionuclides initially introduced in soluble form to the water of the microcosms.

Table 3-5 presents the weight of fauna and suspended material used for mass balance calculations.

Tables 3-6 to 3-10 present the mass balances for each radionuclide.

Student's t-test was used to determine if the control microcosm water and sediment radionuclide concentration were significantly different from the range of radionuclide concentrations found in the water and sediment of the experimental microcosms after three months of profundal fauna activity.

TABLE 3-1

Radionuclides in the Water of Experimental and Control Profundal Microcosms

	Total Uranium (ug/L)	Radium-226 (Bq/L)	Thorium-228 (Bq/L)	Lead-210 (Bq/L)	Polonium-210 (Bq/L)
Initial Conc. in Water	1200	44	35	44	44
Microcosm 1	340	2.7±0.13	0.021±0.011	L0.50	0.24±0.04
Microcosm 2	340	0.21±0.02	0.019±0.009	L0.50	0.03±0.01
Microcosm 3	180	0.17±0.01	0.023±0.01	L0.50	1.5±0.1
Exp. Microcosm Avg.	300	1.0	0.021	L0.50	0.59
Microcosm 4 (Control)	780	6.9±0.2	0.30±0.03	L0.50	0.60±0.07
Control Leachate	L0.50	0.31	0.14	2.5	0.76

1) L = less than or equal to.
2) ± variation reflects the statistical precision of counting using the activity of a tracer and activity of the radionuclide being analyzed.
3) detection limit for lead-210 was the result of the volume of water (one litre) used for analysis.
4) values are the result of single sample analyses.

TABLE 3-2

Radionuclides in the Sediment of Experimental and Control Profundal Microcosms

	Total Uranium (ug/L)	Radium-226 (Bq/L)	Thorium-228 (Bq/L)	Lead-210 (Bq/L)	Polonium-210 (Bq/L)
Initial Conc. in Water	1.2	0.044	0.035	0.044	0.044
Microcosm 1	3.6	0.28±0.02	0.11±0.01	0.27±0.03	0.46±0.03
Microcosm 2	5.6	0.64±0.03	0.35±0.02	0.84±0.05	0.94±0.04
Microcosm 3	4.3	0.18±0.02	0.12±0.01	0.30±0.03	0.35±0.03
Exp. Microcosm Avg.	4.5	0.37	0.19	0.47	0.58
Microcosm 4 (Control)	2.4	0.16±0.01	0.030±0.01	L0.20	0.14±0.01
Relative Concentration Factor	4X	8X	5X	10X	13X

1) ± variation reflects the statistical precision of counting using the activity of a tracer and activity of the radionuclide being analyzed.
2) values are the result of single sample analyses.

TABLE 3-3

Radionuclides Associated with the Suspended Material
of Experimental and Control Profundal Microcosms

	Total Uranium (ug/L)	Radium-226 (Bq/L)	Thorium-228 (Bq/L)	Lead-210 (Bq/L)	Polonium-210 (Bq/L)
Initial Conc. in Water	1.2	0.044	0.035	0.044	0.044
Microcosm 1	140	81±11*	4.7±4.4	L1.0	75±11
Microcosm 2	820	1.4±0.6	1.5±0.7	L1.0	8.0±2.0
Microcosm 3	730	1.8±0.7	6.0±0.8	250±17*	30.±7
Exp. Microcosm Avg.	560	1.6	4.1	L1.0	38.
Microcosm 4 (Control)	18	2.5±0.3	4.7±0.4	12	11±0.5
Relative Concentration Factors	475X	35X	115X	280X	860X

* Data not used.
** Using control microcosm.

1) L = Less than or equal to.
2) Detection limit for lead-210 was the result of the small mass of sample available for analysis.
3) Values are the result of single sample analyses.
4) ± variation reflects the statistical precision of counting using the activity of a tracer and activity of the radionuclide being analyzed.

TABLE 3-4

Radionuclides Associated with the Fauna
of Experimental Profundal Microcosms

	Total Uranium (ug/L)	Radium-226 (Bq/L)	Thorium-228 (Bq/L)	Lead-210 (Bq/L)	Polonium-210 (Bq/L)
Initial Conc. in Water	1.2	0.044	0.035	0.044	0.044
Microcosm 1	23	6.6±0.8	2.6±0.2	L1.0	21±0.4
Microcosm 2	16	2.4±0.4	2.2±0.2	L1.0	22±0.2
Microcosm 3	21	11±0.8	2.5±0.2	3.2±0.3	26±0.8
Exp. Microcosm Avg.	20	6.3	2.4	1.1	23
Relative Concentration Factors	15X	150X	70X	25X	525X

1) L = Less than or equal to.
2) Detection limit for lead-210 was the result of the small mass of sample available for analysis.
3) Values are the result of single sample analyses.
4) ± variation reflects the statistical precision of counting using the activity of a tracer and activity of the radionuclide being analyzed.

TABLE 3-5

Components of Profundal Microcosms
Used for Mass Balances

	Fauna as Dry Weight (g)	Estimated Total Suspended Material (Dry wt.) in Microcosm (g)
Microcosm 1	0.2430	0.0720
Microcosm 2	0.4906	0.3984
Microcosm 3	0.3765	0.0960
Exp. Microcosm Avg.	0.3700	0.1888
Microcosm 4 (Control)	-	3.2144

TABLE 3-6

Uranium Mass Balances for Profundal Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms			
			1	2	3	Mean
Water	32,000 ug (1200 ug/L)	21,000 ug (780 ug/L)	9200 ug (340 ug/L)	9200 ug (340 ug/L)	4900 ug (180 ug/L)	7700 ug (290 ug/L))
Sediment		2400 ug (2.4 ug/g)	3600 ug (3.6 ug/g)	5600 ug (5.6 ug/g)	4300 ug (4.3 ug/g)	4500 ug (4.5 ug/g)
Suspended Material		58 ug (18 ug/g)	10 ug (140 ug/g)	330 ug (820 ug/g)	70 ug (730 ug/g)	140 ug (560 ug/g)
Fauna			5.6 ug (23 ug/g)	8.1 ug (16 ug/g)	7.7 ug (21 ug/g)	7.1 ug (20 ug/g)
Leachate		? (L 0.5 ug/g)	?	?	?	?
Total		23,000 ug/g	13,000 ug	15,000 ug	9300 ug	12,000 ug

L = less than or equal to
XXX = Total amount in microcosm component
(XXX) = Concentration in microcosm component

TABLE 3-7

Radium-226 Mass Balances for Profundal Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms			
			1	2	3	Mean
Water	1200 Bq (44 Bq/L)	190 Bq (6.9 Bq/L)	73 Bq (2.7 Bq/L)	5.7 Bq (0.21 Bq/L)	4.6 Bq (0.17 Bq/L)	28 Bq (1.0 Bq/L)
Sediment		160 ug (0.16 Bq/g)	280 ug (0.28 Bq/g)	640 ug (0.64 Bq/g)	180 ug (0.18 Bq/g)	370 ug (0.37 Bq/g)
Suspended Material		8.1 Bq (2.5 Bq/g)	5.80 Bq (81 Bq/g)*	0.56 Bq (1.4 Bq/g)	0.17 Bq (1.8 Bq/g)	0.37 Bq (1.6 Bq/g)
Fauna			1.6 Bq (6.6 Bq/g)	1.2 Bq (2.4 Bq/g)	4.1 Bq (11 Bq/g)	2.3 Bq (6.7 Bq/g)
Leachate		8.4 Bq (0.31 Bq/L)	8.4 Bq	8.4 Bq	8.4 Bq	8.4 Bq
Total		370 Bq	370 Bq	660 Bq	200 Bq	400 Bq

* Data not used for calculating Mean

XXX = Total amount in microcosm component

(XXX) = Activity per unit of microcosm component

TABLE 3-8

Thorium-228 Mass Balances for Profundal Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms			
			1	2	3	Mean
Water	950 Bq (35 Bq/L)	8.1 Bq (0.30 Bq/L)	0.57 Bq (0.021 Bq/L)	0.51 Bq (0.019 Bq/L)	0.62 Bq (0.023 Bq/L)	0.57 Bq (0.021 Bq/L)
Sediment		30 Bq (0.030 Bq/g)	110 Bq (0.11 Bq/g)	350 Bq (0.35 Bq/g)	120 Bq (0.12 Bq/g)	190 Bq (0.19 Bq/g)
Suspended Material		15 Bq (4.7 Bq/g)	0.34 Bq (4.7 Bq/g)	0.58 Bq (1.5 Bq/g)	0.58 Bq (6.0 Bq/g)	0.50 Bq (4.1 Bq/g)
Fauna			0.64 Bq (2.6 Bq/g)	1.1 Bq (2.2 Bq/g)	0.95 Bq (2.5 Bq/g)	0.90 Bq (2.4 Bq/g)
Leachate		3.8 Bq (0.14 Bq/L)	3.8 Bq	3.8 Bq	3.8 Bq	3.8 Bq
Total		57 Bq	120 Bq	360 Bq	130 Bq	200 Bq

XXX = Total amount in mocrocosm component
(XXX) = Activity per unit of microcosm component

TABLE 3-9

Lead-210 Mass Balances for Profundal Micrpcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms			
			1	2	3	Mean
Water	1200 Bq (44 Bq/L)	? (L 0.50 Bq/L)	? (L 0.50 Bq/L)	? (L 0.50 Bq/L)	? (L 0.50 Bq/L)	? (L 0.50 Bq/L)
Sediment		? (L 0.20 Bq/g)	270 Bq (0.27 Bq/g)	840 Bq (0.84 Bq/g)	300 Bg (0.30 Bq/g)	470 Bq (0.47 Bq/g)
Suspended Material		40 Bq (12 Bq/g)	? (L 1.0 Bq/g)	? (L 1.0 Bq/g)	24 Bq (250 Bq/g)*	? (L 1.0 Bq/g)
Fauna			? (L 1.0 Bq/g)	? (L 1.0 Bq/g)	1.20 Bq (3.2 Bq/g)	? (1.1 Bq/g)
Leachate		68 Bq (2.5 Bq/L)	68 Bq	68 Bq	68 Bq	68 Bq
Total		100 Bq	340 Bq	910 Bq	390 Bq	540 Bq

* Data not used for calculating Mean.
L = Less than or equal to
XXX = Total amount in microcosm component
(XXX) = Activity per unit of microcosm component

TABLE 3-10

Polonium-210 Mass Balances for Profundal Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms			
			1	2	3	Mean
Water	1200 Bq (44 Bq/L)	16 Bq (0.60 Bq/L)	6.5 Bq (0.24 Bq/L)	0.81 Bq (0.030 Bq/L)	41 Bq (1.5 Bq/L)	16 Bq (0.59 Bq/L)
Sediment		140 Bq (0.14 Bq/g)	460 Bq (0.46 Bq/g)	940 Bq (0.94 Bq/g)	350 Bq (0.35 Bq/g)	580 Bq (0.58 Bq/g)
Suspended Material		37 Bq (11 Bq/g)	5.4 Bq (75 Bq/g)	3.2 Bq (8.0 Bq/g)	2.9 Bq (30 Bq/g)	3.8 Bq (38 Bq/g)
Fauna			1.5 Bq (21 Bq/g)	8.8 Bq (22 Bq/g)	2.5 Bq (26 Bq/g)	4.3 Bq (23 Bq/g)
Leachate		21 Bq (0.76 Bq/L)	21 Bq	21 Bq	21 Bq	21 Bq
Total		210 Bq	490 Bq	970 Bq	420 Bq	630 Bq

XXX = Total amount in microcosm component
(XXX) = Activity per unit of microcosm component

332 MASS BALANCES

Mass balances for the profundal microcosms were very poor in relation to the amount of radionuclide added. Generally, less than 50% of the radionuclides introduced to the microcosms could be accounted for in summing of the microcosm components. This resulted from the wide variability of radionuclide activities reported for the water and sediment components and the inability to define the actual quantity of sediment sampled.

The majority of the total quantity or activity of radionuclides in the profundal microcosms occured in the water and sediment components.

Although, the mass balances did not indicate the exact mass distribution of radionuclides within the profundal microcosms, the microcosms did demonstrate:

- the transfer of radionuclides from the water to the sediment;
- the accumulation of radionuclides from the water in the fauna;
- an apparent inverse relationship between polonium-210 activity and the dry weight of suspended material;
- an apparent inverse relationship between both uranium concentration and thorium-228 activity and the dry weight of fauna; and

Results of the radionuclide distributions in the profundal microcosms will be discussed for each individual radionuclide in the following sections.

333 URANIUM

.1 Water

The concentration of uranium in the control microcosm (780 ug/L) was significantly different from the range of uranium concentrations in the experimental microcosms (180 - 340 ug/L) at the 0.10 level. This difference does not exist at the 0.05 level. Thus, the presence of a profundal community apparently has an effect on the removal of uranium from water.

.2 Sediment

There was no statistically significant difference (at either the 0.05 or 0.1 level) between the sediment uranium concentration in the control microcosm (2.4 ug/g) and the range of concentrations in the experimental microcosms (3.6 to 5.6 ug/g). Relative to the initial water concentration, uranium was approximately four times more concentrated in the sediment. This lack of a difference may have been caused by the depth of the sediment cores taken for analysis. If only the surface one centimeter of the core had been analyzed, a difference between the control and experimental microcosms might have become obvious. This increase in sediment uranium concentration would be expected given the significantly lower concentrations of uranium in the water of the experimental microcosms.

.3 Suspended Material

The concentration of uranium associated with suspended material in the experimental profunal microcosms ranged from 144 to 823 ug/g, and averaged 567 ug/g. The control had a much lower concentration (17.9 ug/g), possibly due to the substantially higher amount of suspended material in this microcosm. The average uranium concentration associated

with suspended material for the experimental microcosms was 475 times the initial water concentration.

.4 Fauna

The concentration of uranium associated with the fauna of the profundal microcosms ranged from 16 to 23 ug/g and averaged 20.0 ug/g. Although only three data points were available, there appeared to be an inverse relationship between the weight of the fauna and its associated uranium concentrations. Linear regression analysis demonstrated a regression coefficient of -0.983 for the variables and defined the relationship by:

$$Y = -26.433X + 29.748$$

Where Y is the concentration of uranium (ug/g) associated with the grams dry weight of fauna (X).

.5 Distribution of Uranium in Microcosms

Although the highest concentration of uranium within the microcosm was associated with the suspended material (average 560 ug/g) this was only 0.8% of the uranium which could be accounted for by summing the microcosm components (Table 3-6). The majority of the uranium introduced appeared to stay dissolved in the water (average 290 ug/L). The large volume of this microcosm component produced 64% of the uranium accounted for in the mass balance (i.e. 12,000 ug).

The sediment (average 4.5 ug/g) accounted for 38% of the total microcosm uranium. The fauna (average 20 ug/g) accounted for only 0.06% of the total microcosm uranium.

By contrast, the control microcosm water accounted for 90% of the total microcosm uranium (i.e. 23,000 ug). The more turbid control

microcosm had a lower concentration of uranium in the suspended sediment (18 ug/g) than the experimental microcosms and this component accounted for only 0.2% of the microcosm uranium. Due to the large amount of sediment relative to the other microcosm components, its uranium concentration (2.4 ug/g) accounted for 10% of the total microcosm uranium.

334 RADIUM-226

.1 Water

The radium-226 activity in the water of the control microcosm (6.9 Bq/L) was significantly higher (at the 0.1 level) than the range of values in the experimental microcosms. This difference was not observed at the 0.05 level. Thus, it appears that the presence of a profundal community has an influence on the removal of radium-226 from water.

.2 Sediment

There was no significant difference between the radium-226 activity in the control microcosm (0.16 Bq/g) and the range of activities in the experimental microcosms (0.18 to 0.64 Bq/g). Relative to the initial water activity, radium-226 was eight times more concentrated in the sediment. This may have been due to the depth of the sediment cores taken for analyses. A more surficial core (i.e. the top one centimeter) may have yielded differences between the control and experimental microcosms, complementing the differences observed in the water.

.3 Suspended Material

The activities of radium-226 in experimental microcosms 2 and 3 were 1.4 and 1.8 Bq/g, respectively. Microcosm 1, however, had an activity of 81 Bq/g. This large value could not be explained and its inclusion in the data for calculation of a microcosm mean could not be

justified. The control microcosm had a radium-226 activity of 2.5 Bq/g. The mean radium-226 activity of the experimental microcosms suspended material was 35 times the initial water activity.

.4 Fauna

The activities of radium-226 associated with the fauna of the profundal microcosms ranged from 2.4 to 11 Bq/g and averaged 6.6 Bq/g. The average activity of radium-226 associated with the fauna was 150 times the initial activity of the water.

.5 Distribution of Radium-226 in Microcosms

The highest specific activity of radium-226 was found in the faunal component (6.7 Bq/g) but accounted for less than one percent of the total microcosm activity (400 Bq) (Table 3-7). By contrast, the lowest radium-226 activity (excluding the water) was found in the experimental microcosm sediments, but due to its large mass, it accounted for 93% of the total microcosm activity. Suspended material (1.6 Bq/g) accounted (on average) for less than 0.1% of the total activity in the experimental microcosms. Water (1.03 Bq/g) accounted for 7% of the experimental microcosm activity.

Water in the control microcosm (6.9 Bq/g) accounted for 51% of the total microcosm activity (370 Bq). While this seems substantially different from the experimental microcosms, the high activity in microcosm 1 (2.7 Bq/g) prevented the difference from being statistically significant. The suspended material in the control (2.5 Bq/g) accounted for 2% of the total microcosm activity. The control microcosm sediment (0.16 Bq/g) accounted for 43% of the total microcosm activity. The control leachate accounted for 2% of the total control and experimental microcosm radium-226 activity.

335 THORIUM-228

.1 Water

The activity of thorium-228 in the control microcosm water (0.30 Bq/L) was significantly greater than the range of activities in the experimental microcosms (0.019 to 0.023 Bq/L). Because the control microcosm lacked any fauna and had sterilized sediment, it could be concluded that the presence of the profundal community and unsterilized sediment lowered the amount of thorium-228 in the water of the experimental microcosms. However, the control microcosm was also more turbid than the experimental microcosms. This could have increased the thorium-228 activity in the control microcosm water by providing a larger surface area for sorption-desorption equilibrium reactions, resulting in a higher water activity. However, given the short time frame of the experiment it is not known if substantial equilibrium reactions leading to the release of thorium-228 from the suspended material could occur.

.2 Sediment

The difference between the thorium-228 activity in the control microcosm (0.030 Bq/g) and the range of activities in the experimental microcosms (0.11 to 0.35 Bq/g) was not statistically significant (at either the 0.05 or 0.1 level). Again, this lack of difference may have resulted from the analysis of too large a sediment core section. Results from the littoral microcosms demonstrate that the top one centimeter core section would be the most likely sample for detecting differences between control and experimental microcosms. Thorium-228 was, on average, five times more concentrated in the sediment, than in the water.

.3 Suspended Material

The activity of thorium-228 associated with the suspended material in the control microcosm (4.7 Bq/g) was not significantly

different from the experimental microcosms which ranged from 1.5 to 6.0 Bq/g and averaged 4.1 Bq/g. The average thorium-228 activity of the experimental microcosms suspended material was 115 times the initial water activity.

.4 Fauna

The activities of thorium-228 associated with the fauna of the profundal microcosms ranged from 2.2 to 2.6 Bq/g and averaged 2.4 Bq/g. Although only three data points were available, there appeared to be an inverse relationship between the weight of the fauna and its associated thorium-228 activity. Linear regression analysis demonstrated a regression coefficient of -0.958 for the variables and defined the relationship by:

$$Y = -1.555X + 3.038$$

where Y is the activity of thorium-228 (Bq/g) associated with the gram dry weight of fauna (X).

.5 Distribution of Thorium-228 in Microcosms

Thorium-228 had its highest activity associated with the suspended material (4.1 Bq/g) in the experimental microcosms (Table 3-8). However, due to the relatively small amount of this component (average 0.19 g), suspended material accounted for 0.3% of the total microcosm activity (i.e. 200 Bq). The fauna (average 2.4 Bq/g) accounted for 0.5%. Thorium-228 activities in the experimental microcosm water (average 0.021 Bq/g) were extremely low and accounted for 0.3% of the total microcosm thorium-228 activity. Sediment (average 0.19 Bq/g) accounted for 95% of the experimental microcosm thorium-228 activity.

By contrast, the sediment of the control microcosm (0.030 Bq/g) accounted for 53% of the control microcosm total activity (57.0 Bq).

Compared to the experimental microcosms, the water of the control (0.30 Bq/g) made up a much larger portion of the total microcosm activity (14%). The increased amount of suspended material in the control (almost 20 times higher than the average experimental value) accounted for 26% of the total control microcosm activity of thorium-228. The control microcosm leachate accounted for only 7% of the control microcosm thorium-228 activity. This leachate accounted for 2% of the average experimental microcosm total

336 LEAD-210

.1 Water

The activities of lead-210 in all microcosms (including the control) were below detection limits (i.e. less than or equal to 0.50 Bq/L).

.2 Sediment

The control microcosm lead-210 activity was below detection limits (i.e. less than or equal to 0.20 Bq/g). If the detection limit of 0.20 Bq/g is used for the control microcosm, it is not significantly different (at either the 0.05 or 0.1 level) from the range of activities in the experimental microcosms (0.27 to 0.84 Bq/g). On average, lead-210 activity was 10 times more concentrated in the sediments than in the initial water activity.

.3 Suspended Material

The activities of lead-210 associated with suspended material in microcosms 1 and 2 were below detection limits (i.e. less than or equal to 1.0 Bq/g). Microcosm 3, however, was found to have 250 Bq/g associated with this component. An explanation for this high activity

could not be found. The activity in the control microcosm was 12 Bq/g. A concentration factor, relative to the initial water activity, could not be calculated for experimental microcosms 1 and 2, due to their low activities. The suspended material in the control microcosm had a lead-210 activity 280 times the initial water concentration.

.4 Fauna

The activities of lead-210 associated with the fauna of the profundal microcosms varied from below detection limits (less than or equal to one) to 3.2 Bq/g. On average, the lead-210 activity associated with the fauna was 25 times the initial water activity.

.5 Distribution of Lead-210 in Microcosms

The lead-210 activity in the experimental microcosms was, for all practial purposes, confined to the sediment (average 0.47 Bq/g) which accounted for 87% of the microcosm activity (Table 3-9). The fauna accounted for less than 0.1% of the total microcosm lead-210 activity. The lead-210 activities in the water and in the suspended material were below detection limits. While the activity represented by these components is unknown, judging from their relative weight, they could account for only a very small fraction of the total microcosm lead-210 activity. Lead-210 activity lost to the walls of the microcosm (assessed by leachate) probably accounted for 13% or more.

The activity of the suspended material in the control microcosms accounted for 37% of the total microcosm lead-210 activity. This is probably due to the increased level of suspended material in the control microcosm compared to the experimental microcosm. Both the water and sediment were below detection limits (less than or equal to 0.50 Bq/g and 0.20 Bq/g, respectively). Thus, their respective activities relative to the total microcosm activity cannot be assessed.

The activity of the lead-210 adsorbed to the control microcosm wall, (as estimated by the leachate) accounted for 68% of the total control microcosm lead-210 activity. If this activity is equated to the activity lost to walls of the experimental microcosms, it accounts for 13% of the recovered total microcosm activity in those microcosms.

337 POLONIUM-210

.1 Water

The activity of polonium-210 in the control microcosm (0.60 Bq/L) was not significantly different (at either the 0.05 or 0.1 level) from the range of activities in the experimental microcosms (0.03 to 1.5 Bq/L).

.2 Sediment

The activity of polonium-210 in the control microcosm sediment (0.14 Bq/g) was not significantly different (at either the 0.05 or 0.1 level) from the range of activities in the experimental microcosms (0.35 to 0.94 Bq/g).

.3 Suspended Material

The activities of polonium-210 associated with the suspended material ranged from 8 to 75 Bq/g for all microcosms. Excluding the activity in the control microcosm (11 Bq/g) there was an inverse relationship between the activity of polonium-210 and the weight of suspended material. Linear regression analysis demonstrated a regression coefficient of -0.816 for these variables with the relationship defined by:

$$Y = -2{,}388.877X + 65.139$$

where Y is the activity (Bq/g) of polonium-210 associated with the grams dry weight of suspended material (X).

On average, the suspended material had 860 times the initial polonium-210 water activity.

.4 Fauna

The activities of polonium-210 associated with the fauna of the profundal microcosm ranged from 21 to 26 Bq/g, and averaged 23 Bq/g. On average, the fauna contained approximately 525 times the initial water activity.

.5 Distribution of Polonium-210 in Microcosms

The highest activity of polonium-210 in the experimental microcosms was associated with the suspended material (average 38 Bq/g) (Table 3-10). This component accounted for less than 1% of the total microcosm polonium-210 activity. The fauna (average 23.0 Bq/g) also accounted for less than 1% of the microcosm activity. Water activities were low (average 0.59 Bq/L) and accounted for approximately 3% of the microcosm activity compared with 92% for the sediment (average 0.58 Bq/g).

The sediment in the control microcosm accounted for 67% of the polonium-210 activity. Like the experimental microcosms, polonium-210 reached its highest activity in suspended material (11 Bq/g) and accounted for 18% of the total microcosm activity. Water accounted for approximately 8% of the control microcosm total polonium-210 activity.

The leachate (0.76 Bq/g or 21 Bq total) accounted for 10% of the polonium-210 recovered in the control microcosm. If this activity is equivalent to that lost to the walls in the experimental microcosm, it accounts for 3% of the total experimental microcosms activity.

338 COMPARISON OF RADIONUCLIDES

The observed reduction of the radionuclides in the water of the profundal microcosms was the result of:

- uptake (adsorption or absorption) by the fauna;
- adsorption by suspended material;
- adsorption onto microcosm walls;
- adsorption by the sediment.

The summation of those factors resulted in the removal from the water of the following percentages of the radionuclides in the experimental microcosms:

- Uranium: 74.7%;
- Radium-226: 97.6%;
- Thorium-228: 98.7%;
- Lead-210: 98.9%; and
- Polonium-210: 99.9%.

Relative to the initial concentrations and activities of radionuclides in the water, the sediments of the experimental profundal microcosms, on average, concentrated the radionuclides by the following factors:

- Uranium: 4X;
- Radium-226: 8X;
- Thorium-228: 5X;
- Lead-210: 10X; and
- Polonium-210: 13X.

Although the data is extremely variable and selected individual activities for radium-226 and lead-210 were deleted from consideration, it appears that the suspended material had the ability to concentrate

radionuclides from the water. Relative to the initial water concentration or activity the concentration factors were:

- o Uranium: 475X;
- o Radium-226: 35X;
- o Thorium-228: 115X;
- o Lead-210: 280X; and
- o Polonium-210: 860X.

The relative concentration factors are much greater than those for the sediment. As yet, an explanation cannot be offered for these differences.

Although all the radionuclides were concentrated by the profundal fauna, polonium-210 was concentrated to a much greater extent than the others. The concentrations factors for the fauna relative to the initial water concentration or activity were:

- o Uranium: 15X;
- o Radium-226: 150X;
- o Thorium-228: 70X;
- o Lead-210: 25X; and
- o Polonium-210: 525X.

Of all the components analyzed in the experimental profundal microcosms, uranium, thorium-228 and polonium-210 reached their highest concentrations and activities in the suspended material. Radium-226 and lead-210 attained their highest activities in the fauna of these microcosms.

Inverse or negative relationships were observed for both uranium concentrations and thorium activities associated with the profundal fauna (as dry weight). An inverse relationship was also observed between polonium-210 activity and the associated dry weight of

suspended material. Although the regression coefficient for these relationships are good (i.e. greater than -0.8) the reasons for the relationships cannot be determined.

Figure 3-2 is a graphic representation of the distribution of radionuclides in the control and experimental profundal microcosms.

339 SUMMARY OF FINDINGS

The results of the profundal microcosm experiments can be summarized as follows:

- Thorium-228, demonstrated a statistically significant decrease in the water of the experimental microcosms as compared to the control. Uranium and radium-226 also demonstrated differences between the control and experimental water, but these differences were not as strong as thorium-228;

- The significant difference between the control and experimental water activities of thorium-228 may have been due to the much higher suspended material concentration in the control microcosms;

- The differences between radionuclide concentrations and activities in the profundal control and experimental sediments were not significant. This may have been the result of sampling too deep a sediment core, thereby diluting a possible higher activity in the surface one centimeter with much lower activities deeper in the core;

- As statistically significant differences (at the 0.1 level) were found between the waters of the control and experimental profundal microcosms for uranium and radium-226, it can be

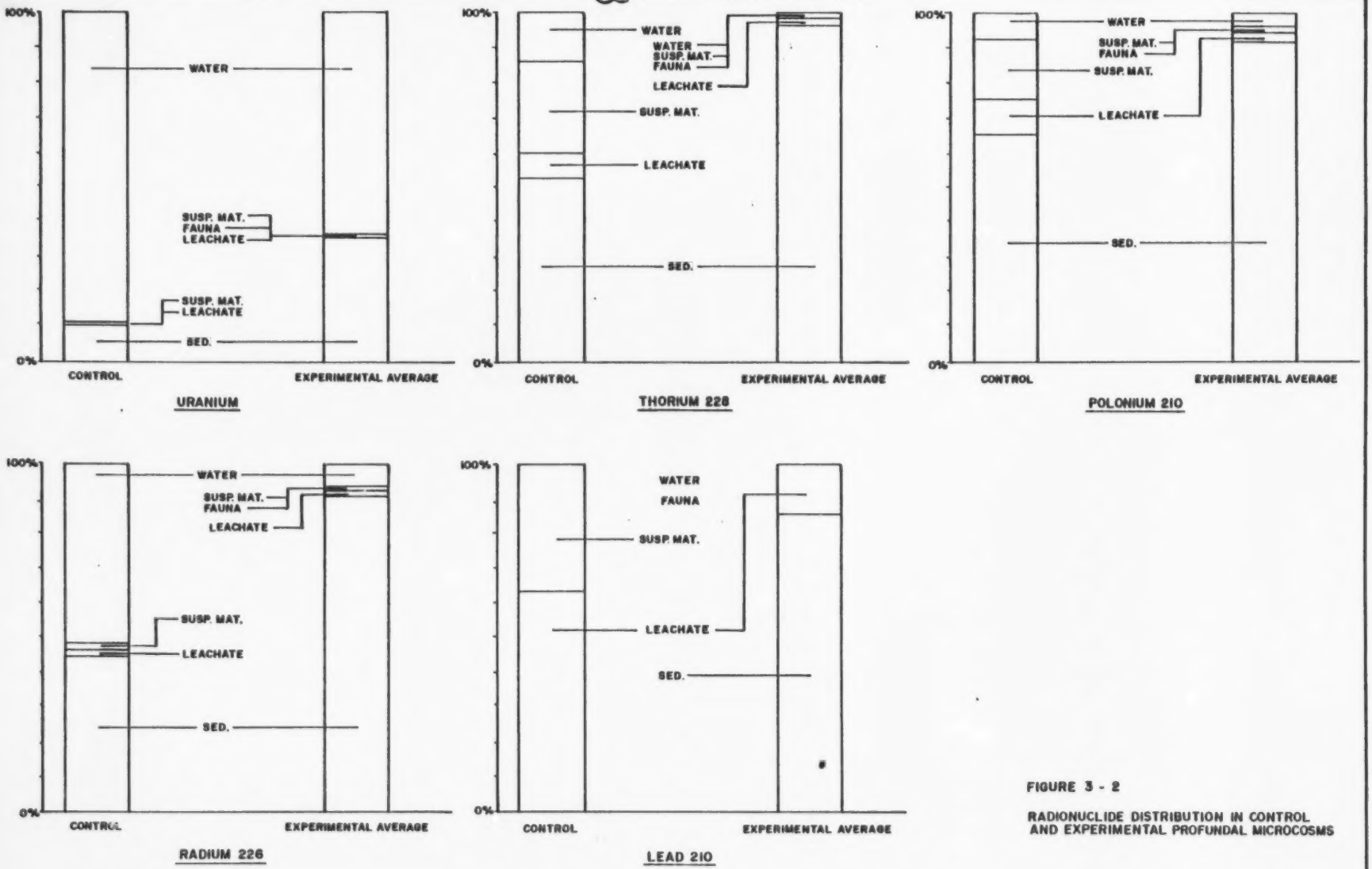

FIGURE 3 - 2

RADIONUCLIDE DISTRIBUTION IN CONTROL AND EXPERIMENTAL PROFUNDAL MICROCOSMS

concluded that the presence of profundal organisms, with the context of the experiment, had an effect on the removal of radionuclides from the water;

- Of the radionuclides examined, uranium remained in solution to a greater extent than the other radionuclides;

- The percentages of the radionuclides (except uranium) removed from the water during the three month experimental period were all in excess of 97%;

- The highest concentrations or activities of all the radionuclides in the profundal microcosms were associated with the suspended material; and

- Although all the radionuclides were found in the fauna, polonium-210 was concentrated (relative to the initial water activity) to a much greater extent than any of the others.

PART 4

LITTORAL MICROCOSMS

PART 4 - LITTORAL MICROCOSMS

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4.1 INTRODUCTION

The littoral region of a lake consists of an interface zone between the land and the open water of the lake.

This area of a lake has the potential for biological interactions with introduced radionuclides because of the high abundance and diversity of biological organisms. Types of organisms associated with the littoral zones of lakes which are known to accumulate radionuclides are:

- o periphyton (Emerson and Hesslein 1973);
- o attached macroalgae (Brierley et al. 1980, Marchyulenene et al. 1972, Marchyulenene 1978, Dusauskene-Duz and Polikarpov 1978);
- o aquatic vascular plants (Mahon and Mathews 1983, Justyn and Stanek 1974, Havlik 1967, 1970); and
- o aquatic invertebrates such as snails, amphipods, and insects (Martin et al. 1967).

In addition, phytoplankton, zooplankton and other invertebrates within the littoral zone also have the potential to remove radionuclides from the water in the same manner as they remove them from the limnetic zone.

The purpose of constructing a series of littoral microcosms was to ascertain the importance of the organisms inhabiting this area of a lake in the removal of radionuclides from water relative to a littoral environment devoid of organisms.

4.2 METHODS AND MATERIALS

Littoral sediment, collected from a local lake, was homogenized in large plastic tubs and equal portions were separated into 87 litre glass aquariums to produce a wedge of sediment approximately 9 cm high, 30 cm wide and extending approximately 45 cm along the long axis of the aquarium. The approximate volume of sediment in each aquarium was 8,500 cm^3. Exactly 500 ml of the homogenized sediment was weighed for a determination of density (1.43 g/ml). This sediment was then dried at 50°C for one week and the density of the dry sediment determined (2.57 g/ml). From these measurements, it was estimated that approximately 8 kg of dry sediment existed in each microcosm. Untreated lake water (approximately 41 litres) was placed in each of six aquariums to completely cover the sediment. A seventh (control) aquarium had approximately 2,500 cm^3 of autoclaved (138 kPa at 150°C for two hours) sediment covered with approximately 41 litres of filtered (0.45 u) lake water. A single small airstone was placed at the end of each aquarium opposite the sediment and connected to a pump for circulation and aeration of the water in the aquarium. A single piece of plate glass was placed over each aquarium to retard evaporation.

Because of the season in which this study was initiated (late winter) well-developed littoral ecosystems were not present for use in the construction of these microcosms. Although some benthic organisms were observed in the aquariums after sediment was added it was decided to develop littoral microcosms within the aquariums by supplying additional organisms from other aquatic habitats and plants from aquarium shops.

Equal numbers of aquatic plants belonging to the genera Vallisneria, Cryptocoryne, Bacopa, Ceratopteris and Echinodorus were placed in each of the six treatment microcosms. As well, annilid worms of the genus Tubifex were also added. After one month under constant illumination, biological activity had greatly increased. A macroalga

(Chara sp.) was observed to be growing from the sediment. Snails also appeared in some of the microcosms (apparently from eggs in the sediment). Amphipods from a local pond were added to each of the six experimental microcosms to increase the variety of organisms present. After the littoral microcosms had developed, the illumination (by cool white 40 watt fluorescent bulbs) was changed from continuous to an 18 hour light, six hour dark cycle.

A diagram of the littoral microcosms used in the study is presented in Figure 4-1.

Approximately six weeks after the sediment and organisms were added to the six experimental aquariums, a biological community of sufficient biomass and diversely had developed which was suitable for the introduction of the following radionuclides:

- 37 Bq radium-226/litre of water (1500 Bq per microcosm);
- 37 Bq lead-210/litre of water (1500 Bq per microcosm);
- 37 Bq polonium-210/litre of water (1500 Bq per microcosm);
- 30 Bq thorium-228/litre of water (1200 Bq per microcosm);
- 1.0 mg uranium-238/litre of water (41 mg per microcosm);

Distilled water was added periodicially to compensate for water loss due to evaporation.

At the conclusion of the three-month experimental period, two-litre water samples were taken from each microcosm. The water was filtered through preweighed 0.45 u membrane filters and submitted for analysis. The filters were dried at 50°C for 24 hours, dessicated for 24 hours and reweighed for a determination of the suspended material weight.

Three sediment cores were collected from each microcosm with a 5.8 cm I.D. plexiglass tube. These cores were removed from the microcosm and pushed up through the top of the plexiglass tube. One centimetre

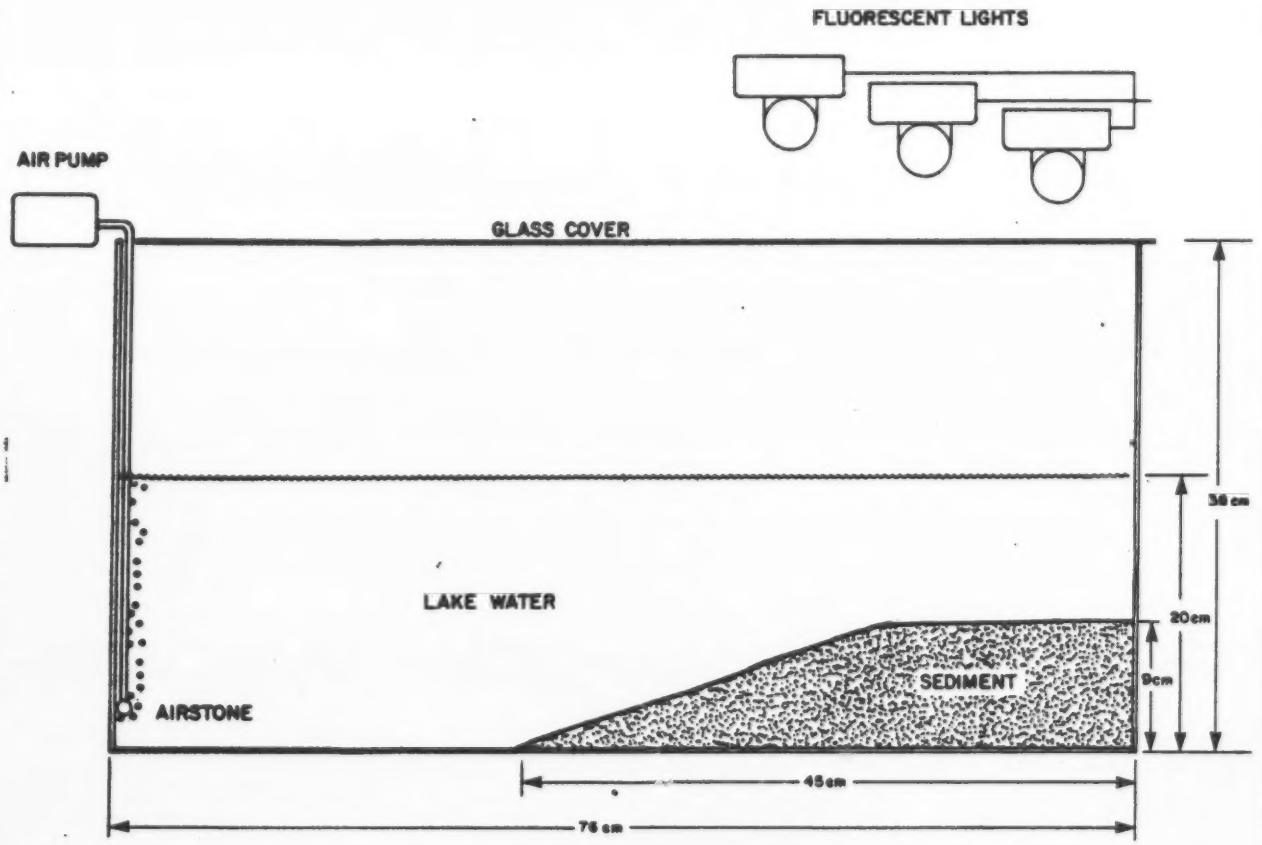

FIGURE 4-1

CROSS-SECTION OF LITTORAL MICROCOSM

sections of sediment core were cut off with a large spatula as the sediment core emerged from the plexiglass tube. Core sections (i.e. 0-1 cm, 1-2 cm, 2-3 cm, etc.) from each of the three sediment cores were combined into a single plastic dish. After mixing and drying, approximately 10 grams of sediment from each plastic dish was taken to form a composite sample for 0-3 cm and 3 cm to microcosm bottom sediment fractions. A change in the scope of the sediment analyses also allowed for the analyses of individual one centimetre sediment core sections for the top three centimetres of sediment from all microcosms.

After sediment cores were removed, the aquatic macrophytes were removed from each microcosm and placed in individual plastic dishes. The macrophyte biomass from each microcosms was dried at 50°C for three days and then weighed. At the end of the experimental period, concern was expressed about the contribution of attached algae (periphyton) on the leaf surface to the radionuclide concentration of the whole plant. Although leaf surfaces of the macrophytes showed no obvious periphytic growth, one plant (Echinodorus sp.) was taken from each microcosm and stripped of its leaves which were then separated into two equal sets based on leaf dimensions. The remainder of the plants were placed with the other macrophyte samples from the appropriate microcosm. One set of leaves was thoroughly wiped with cotton balls to remove as much as possible any periphytic growth. Both sets were then submitted for analysis of uranium, radium-226 and lead-210. Thorium-228 and polonium-210 were not analyzed due to their subordinate importance relative to the other radionuclides and the need to apply available funds to the increased number of sediment analyses.

After removal of the living macrophytes, leaves and stems of plants which had died during the experimental period were collected and placed in plastic dishes. This material, (termed "macrophyte detritus") was dried at 50°C for three days and weighed.

Large members of the fauna were concentrated in the end of each microcosm opposite the sediment wedge and collected with forceps and small pieces of plastic screen. These organisms were placed in preweighed plastic dishes containing isopropyl alcohol. Afterward, the uppermost 4 to 5 cm of sediment was removed and washed (elutriated) to remove the fine silt. The contents of the elutriator (which used a 0.5 mm mesh plastic screen) were then placed in a white porcelain pan and organisms (generally oligochaetes) were removed and placed in the appropriate plastic dish containing the fauna collected earlier. After the sediment from each microcosm had been examined, the fauna samples were dried at 50°C for three days and weighed.

After removal of the remaining sediment from the microcosm, the periphyton attached to the walls of the microcosm was sampled by rubbing with preweighed cotton balls. Cotton balls with the absorbed periphyton from each microcosm were placed in individual plastic dishes and dried at 50°C for 24 hours. The cotton balls were then weighed again for a determination of the biomass of periphyton. Unused cotton balls were also submitted for analysis as sample material blanks.

Although the control littoral microcosm contained sterile sediment and water, a thin film of algal growth formed at the glass water interface during the three-month experimental period. This growth was sampled and submitted for analysis along with the periphytic growth (glass surfaces only) from the experimental microcosms.

Whereas the growth of the periphyton in the control was slow and only recognizable during the last month of the experiment, the periphyton growth in the experimental microcosms was immediate and heavy. During the period of experimental microcosm development, the periphyton developed first and then alternately increased and decreased in biomass during the three-month experimental period. The periphyton present in the experimental microcosms at the time the radionuclides were introduced eventually decreased in biomass (possibly due to grazing and

other factors) until the glass walls were almost devoid of this component. At the time of sampling, a completely new periphyton community had started to develop on the microcosm walls.

A leachate of the control microcosm was not conducted because of the initial concern with only the sediment and water concentrations of radionuclides in the microcosms and the complete coverage of the experimental microcosm walls by periphyton.

4.3 RESULTS AND DISCUSSION

431 INTRODUCTION

Tables 4-1 to 4-9 present the concentrations of radionuclides in the various individual microcosm components (i.e. water, sediment, periphyton, fauna, aquatic macrophytes, suspended material and macrophyte detritus). Also, presented in each table are:

- the average concentration and activities of radionuclides in each microcosm component for the six experimental microcosms;
- the concentration and activities of radionuclides in the control microcosm; and
- the initial calculated concentrations and activities of radionuclides introduced in soluble form to the water of the microcosms.

Table 4-10 presents the weight of various microcosm components used for mass balance determinations.

Tables 4-11 to 4-15 presents the mass balances for each radionuclide.

TABLE 4-1

Radionuclides in the Water of Control and Experimental Littoral Microcosms

	Total Uranium (ug/L)	Radium-226 (Bq/L)	Thorium-228 (Bq/L)	Lead-210 (Bq/L)	Polonium-210 (Bq/L)
Initial Conc. in water	1000	37.0	29.6	37.0	37.0
Microcosm 1	150	0.17±0.02	0.012±0.003	L0.37±0.04	L0.30
Microcosm 2	140	0.29±0.027	0.008±0.004	3.9 ±0.2	L0.30
Microcosm 3	85	0.16±0.020	L0.005	0.50±0.05	L0.30
Microcosm 4	42	0.24±0.022	0.012±0.002	L0.30	L0.30
Microcosm 5	60	0.20±0.032	0.011±0.001	L0.30	L0.30
Microcosm 6	230	0.38±0.052	0.010±0.005	L0.30	L0.30
Exp. Microcosm Avg.	120	0.24	0.009	0.80	L0.30
Microcosm 7 (Control)	420	0.45±0.042	0.015±0.005	L0.30	0.43±0.05

1) L = less than or equal to.
2) Values are the result of single sample analyses.
3) ± variation reflects the statistical precision of counting using the activity of a tracer and activity of the radionuclide being analyzed.
4) Detection limit for lead-210 and polonium-210 was the result of the maximum sample size for which analysis was possible (one litre).

TABLE 4-2

Radionuclides in the Sediments
of Control and Experimental Littoral Microcosms

	Sed. Depth	Total Uranium (ug/g)	Radium-226 (Bq/g)	Thorium-228 (Bq/g)	Lead-210 (Bq/g)	Polonium-210 (Bq/g)
Initial Conc. in water		1.00	0.037 0	0.0296		
Microcosm 1	0-3	5.7	0.47 ±0.03	0.22 ±0.02	0.33±0.03	0.45±0.03
	3-B	1.6	0.039±0.008	0.024±0.005	L0.20	0.13±0.01
Microcosm 2	0-3	1.9	*0.077±0.013	*0.032±0.01	*L0.20	*0.22±0.02
	3-B	1.8	0.021±0.006	L0.010	L0.20	0.07±0.01
Microcosm 3	0-3	5.8	0.34 ±0.03	0.26 ±0.02	0.32±0.03	0.53±0.03
	3-B	1.6	0.050±0.01	0.025±0.007	*0.45±0.04	0.22±0.02
Microcosm 4	[illegible]	4.8	0.31 ±0.03	0.26 ±0.02	0.78±0.05	0.48±0.03
	3-B	2.2	0.085±0.013	0.052±0.008	*1.21±0.06	0.12±0.01
Microcosm 5	0-3	5.5	0.41 ±0.03	0.50 ±0.03	0.64±0.04	0.62±0.03
	3-B	2.2	0.090±0.02	0.027±0.007	*1.4 ±0.1	0.09±0.01
Microcosm 6	0-3	4.7	0.38 ±0.04	0.28 ±0.02	0.40±0.03	0.36±0.03
	3-B	1.5	0.036±0.01	0.026±0.005	L0.20	0.09±0.01
Exp. Microcosm Avg.	0-3	5.3	0.38	0.30	0.49	0.49
	3-B	1.8	0.061	0.026	L0.20	0.12
Microcosm 7 (Control)	0-3	3.5	0.36 ±0.02	0.26 ±0.02	0.34 ±0.03	0.45±0.03
	3-B	1.8	0.043±0.01	0.028±0.006	L0.20	0.16±0.03
Relative Concentration Factors	0-3	5X	10X	10X	10X	10X
	3-B	2X	1X	1X	L5X	5X

1) L = less than or equal to.
2) B = bottom of core, which ranged in depth from 6 to 9 cm.
3) Values are the result of single sample analyses.
4) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.
5) Detection limit for lead-210 was the result of the small mass of this component analysed

TABLE 4-3

Uranium, Radium-226, and Lead-210 Distribution in the Top Three Centimetres of the Littoral Microcosm Sediments

	Sediment Depth (cm)	Total Uranium (ug/g)	Radium-226 (Bq/g)	Lead-210 (Bq/g)
Initial Conc. in Water		1.0	0.037	0.037
Microcosm 1	0-1	12.	0.76±0.03	0.37±0.05
	1-2	6.2	0.53±0.03	0.25±0.04
	2-3	1.9	0.25±0.02	L0.05
Microcosm 2	0-1	6.6	0.28±0.02	L0.05
	1-2	2.0	0.09±0.01	L0.05
	2-3	1.1	0.13±0.01	0.10±0.04
Microcosm 3	0-1	6.0	0.33±0.02	0.25±0.04
	1-2	11.	0.54±0.03	0.31±0.04
	2-3	10.	0.46±0.02	0.24±0.03
Microcosm 4	0-1	7.5	0.66±0.03	0.74±0.05
	1-2	6.8	0.36±0.02	0.32±0.04
	2-3	10.0	0.51±0.03	0.25±0.04
Microcosm 5	0-1	7.4	0.47±0.02	0.76±0.05
	1-2	6.4	0.40±0.02	0.36±0.04
	2-3	6.6	0.45±0.02	0.27±0.04
Microcosm 6	0-1	21.	1.4 ±0.04	0.96±0.06
	1-2	4.4	0.53±0.03	0.16±0.03
	2-3	1.8	0.11±0.01	L0.05
Exp. Microcosm Avg.	0-1	10.	0.64	0.51
	1-2	6.1	0.41	0.23
	2-3	5.2	0.32	0.16
Microcosm 7 (Control)	0-1	6.6	0.60±0.03	0.73±0.05
	1-2	4.7	0.32±0.02	0.22±0.04
	2-3	3.2	0.12+0.01	0.13±0.03

1) L = less than or equal to.
2) Values are the result of single sample analyses.
3) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.
4) Detection limit for lead-210 was the result of the small mass of this component analyzed.

TABLE 4-4

Radionuclides Associated with Periphyton on Littoral Microcosm Walls

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Thorium-228 (Bq/g)	Lead-210 (Bq/g)	Polonium-210 (Bq/g)
Initial Conc. in Water	1.0	0.037	0.038	0.037	0.037
Microcosm 1	100	18±1.1	2.8±0.1	9.5±0.3	6.4±0.2
Microcosm 2	75	86±4.0	3.3±0.2	8.0±0.7	15±1
Microcosm 3	79	285±18	4.2±0.6	237±10	34±2
Microcosm 4	79	24±2.0	2.7±0.1	1.6±0.1	4.0±0.2
Microcosm 5	61	32±1.5	2.3±0.1	5.8±0.4	5.6±0.2
Microcosm 6	66	58±2.5	1.2±0.2	18±1	8.0±0.5
Exp. Microcosm Avg.	77	84	2.7±1.3	8.5	12
Microcosm 7 (Control)	110	89±5	20±1	138±5	66±2
Relative Concentration Factor (experimental microcosms)	80X	2300X	90X	1300X	300X
Collection Material Blank	L0.5	0.02	L0.01	L1.0	0.04

1) L = less than or equal to.
2) Values are the result of single sample analyses.
3) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.

TABLE 4-5

Radionuclides Associated with Fauna from Littoral Microcosms

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Thorium-228 (Bq/g)	Lead-210 (Bq/g)	Polonium-210 (Bq/g)
Initial Conc. in Water	1.00	0.037	0.030	0.037	0.037
Microcosm 1	L0.50	0.82±0.38	2.10±0.3	L1.0	6.1±0.5
Microcosm 2	2.6	1.6 ±0.2	0.27±0.02	L1.0	4.6±0.1
Microcosm 3	4.0	1.6 ±0.2	0.62±0.05	4.3±0.2	4.3±0.1
Microcosm 4	4.0	0.72±0.16	0.39±0.04	3.1±0.3	5.7±0.2
Microcosm 5	2.5	0.67±0.14	0.40±0.03	1.6±0.1	5.3±0.2
Microcosm 6	2.4	5.1 ±0.2	0.59±0.05	1.0±0.1	8.2±0.2
Exp. Microcosm Avg.	2.6	1.8	0.73	1.6	5.7
Relative Concentration Factors	3X	45X	25X	45X	150X

1) L = less than or equal to.
2) Values are the result of single sample analyses.
3) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.

TABLE 4-6

Radionuclides Associated with Aquatic Macrophytes from Littoral Microcosms

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Thorium-228 (Bq/g)	Lead-210 (Bq/g)	Polonium-210 (Bq/g)
Initial Conc. in Water	1.0	0.037	0.030	0.037	0.037
Microcosm 1	18	7.4±0.7	0.93±0.04	4.5±0.2	2.6±0.1
Microcosm 2	32	4.1±0.4	0.76±0.04	3.3±0.2	2.8±0.1
Microcosm 3	14	5.1±0.2	0.24±0.01	1.1±0.1	1.6±0.1
Microcosm 4	7.6	4.4±0.4	0.33±0.02	2.3±0.1	1.6±0.1
Microcosm 5	9.2	7.0±0.3	0.33±0.02	1.8±0.1	1.5±0.1
Microcosm 6	9.6	7.6±0.4	0.77±0.04	4.0±0.2	3.2±0.1
Exp. Microcosm Avg.	15	5.9	0.56	2.8	2.2
Relative Concentration Factors	15X	160X	20X	75X	60X

1) Uranium Analysis by Neutron Activation Analysis - direct count.
2) Values are the result of single sample analyses.
3) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.

TABLE 4-7

Comparison of Radionuclides from
Macrophyte Leaves (*Echinodorus* sp.)
with and without Periphyton

	Uranium (ug/g)	Radium-226 (Bq/g)	Lead-210 (Bq/g)
Leaves with Periphyton	13.8	3.2±0.2	1.7±0.1
Leaves without Periphyton	L0.4	2.9±0.2	1.4±0.1

1) L = less than or equal to.
2) Uranium analysis by Delayed Neutron Activation Analysis - direct count.
3) Values are the result of single sample analyses.
4) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.

TABLE 4-8

Radionuclides Associated with Suspended Material from Littoral Microcosms

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Lead-210 (Bq/g)
Initial Conc. in Water	1.0	0.0370	0.0370
Microcosm 1	12	0.92±0.2	L0.80
Microcosm 2	25	4.7±0.4	L0.80
Microcosm 3	5.4	0.90±0.2	L0.80
Microcosm 4	14	3.2±0.3	L0.80
Microcosm 5	4.0	1.8±0.4	L0.80
Microcosm 6	67	19±3	L0.80
Exp. Microcosm Avg.	21	5.7	L0.80
Microcosm 7 (Control)	31	3.7 ±0.93	L0.800
Relative Concentration Factors	25X	150X	L20X

1) L = less than or equal to.
2) Values are the result of single sample analyses.
3) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.
4) Detection limit for lead-210 was the result of the small mass of this component analyzed.

TABLE 4-9

Radionuclides Associated with Macrophyte
Detritus from Littoral Microcosms

	Total Uranium (ug/g)	Radium-226 (Bq/g)	Lead-210 (Bq/g)
Initial Conc. in Water	1.0	0.037	0.037
Microcosm 1	15	3.9±0.2	2.2 ±0.1
Microcosm 2	140	3.5±0.2	2.3 ±0.1
Microcosm 3	56	5.0±0.3	1.2 ±0.1
Microcosm 4	89	1.0±0.1	0.80±0.03
Microcosm 5	59	5.3±0.3	3.1 ±0.1
Microcosm 6	74	2.4±0.4	1.8 ±0.1
Exp. Microcosm Avg.	95	3.5	1.9
Relative Concentration Factors	95X	95X	50X

1) ± variation reflects the statistical precision of counting using the acitivity of a tracer and activity of the radionuclide being analyzed.

TABLE 4-10

Components of Littoral Microcosms Used for Mass Balances

	Periphyton as Dry Weight (g)	Aquatic Macrophytes as Dry Weight (g)	Macrophyte Detritus as Dry Weight (g)	Fauna as Dry Weight (g)	Estimated Total Suspended Material (g)
Microcosm 1	1.7813	5.776	1.341	0.158	1.09
Microcosm 2	0.1493	8.292	1.634	2.488	0.51
Microcosm 3	0.0506	7.108	1.296	1.778	1.11
Microcosm 4	0.9909	9.759	2.865	0.719	0.744
Microcosm 5	0.8237	10.549	1.433	1.017	1.111
Microcosm 6	0.3638	16.099	6.865	1.852	0.210
Exp. Microcosm Avg.	0.6933	9.5972	2.5723	1.3353	0.796
Microcosm 7 (Control)	0.1525	-	-	-	0.428

TABLE 4-11

Uranium Mass Balances for Littoral Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms						
			1	2	3	4	5	6	Mean
Water	41,000 ug (1000 ug/L)	17,000 ug (420 ug/L)	6,200 ug (150 ug/L)	5,500 ug (140 ug/L)	3,500 ug (85 ug/L)	1,700 ug (42 ug/L)	2,500 ug (60 ug/L)	9,400 ug (230 ug/L)	4,800 ug (120 ug/L)
Sediment (0-3 cm)		9,500 ug (3.5 ug/g)	16,000 ug (5.7 ug/g)	*5,200 ug *(1.9 ug/g)	16,000 ug (5.8 ug/g)	13,000 ug (4.8 ug/g)	15,000 ug (5.5 ug/g)	13,000 ug (4.7 ug/g)	13,000 ug (5.3 ug/g)
Sediment (3-8)		7,200 ug (1.8 ug/g)	6,400 ug (1.6 ug/g)	7,200 ug (1.8 ug/g)	6,400 ug (1.6 ug/g)	8,800 ug (2.2 ug/g)	8,800 ug (2.2 ug/g)	6,000 ug (1.5 ug/g)	7,300 ug (1.8 ug/g)
Suspended Material		13 ug (31 ug/g)	13 ug (12 ug/g)	12 ug (25 ug/g)	6.0 ug (5.4 ug/g)	10 ug (14 ug/g)	4.4 ug (4.0 ug/g)	14 ug (67 ug/g)	9.9 ug (21 ug/g)
Fauna			*? *(L0.50 ug/g)	6.5 ug (2.63 ug/g)	7.1 ug (3.97 ug/g)	2.8 ug (3.89 ug/g)	2.5 ug (2.46 ug/g)	4.5 ug (2.43 ug/g)	4.7 ug (2.56 ug/g)
Macrophytes			100 ug (18 ug/g)	270 ug (32 ug/g)	100 ug (14 ug/g)	74 ug (7.6 ug/g)	97 ug (9.2 ug/g)	160 ug (9.6 ug/g)	130 ug (15 ug/g)
Periphyton		17 ug (110 ug/g)	180 ug (100 ug/g)	11 ug (75 ug/g)	4.0 ug (79 ug/g)	78 ug (79 ug/g)	50 ug (61 ug/g)	24 ug (66 ug/g)	58 ug (77 ug/g)
Macrophyte Detritus			21 ug (15.3 ug/g)	230 ug (140 ug/g)	73 ug (56.3 ug/g)	260 ug (89.0 ug/g)	84 ug (58.6 ug/g)	510 ug (74.3 ug/g)	200 ug (95.2 ug/g)
Total		34,000 ug	29,000 ug	18,000 ug	26,000 ug	24,000 ug	27,000 ug	29,000 ug	27,000 ug

* Data not used to calculate mean
L = less than or equal to

XXX = Total amount in microcosm component
(XXX) = Concentration in microcosm component

TABLE 4-12

Radium-226 Mass Balances for Littoral Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms						
			1	2	3	4	5	6	Mean
Water	1500 Bq (37.0 Bq/L)	19 Bq (0.45 Bq/L)	6.8 Bq (0.17 Bq/L)	12 Bq (0.29 Bq/L)	6.4 Bq (0.16 Bq/L)	9.8 Bq (0.24 Bq/L)	8.3 Bq (0.20 Bq/L)	16 Bq (0.38 Bq/L)	9.8 Bq (0.238 Bq/L)
Sediment (0-3 cm)		980 Bq (0.36 Bq/g)	1300 Bq (0.47 Bq/g)	*210 Bq *(0.077 Bq/g)	930 Bq (0.34 Bq/g)	840 Bq (0.31 Bq/g)	1100 Bq (0.41 Bq/g)	1000 Bq (0.38 Bq/g)	860 Bq (0.38 Bq/g)
Sediment (3-8)		170 Bq (0.04 Bq/g)	160 Bq (0.039 Bq/g)	84 Bq (0.021 Bq/g)	200 Bq (0.050 Bq/g)	340 Bq (0.085 Bq/g)	360 Bq (0.090 Bq/g)	140 Bq (0.036 Bq/g)	210 Bq (0.06 Bq/g)
Suspended Material		1.6 Bq (3.7 Bq/g)	1.00 Bq (0.92 Bq/g)	2.4 Bq (4.7 Bq/g)	1.0 Bq (0.90 Bq/g)	2.4 Bq (3.2 Bq/g)	2.0 Bq (1.8 Bq/g)	4.0 Bq (19 Bq/g)	2.1 Bq (5.7 Bq/g)
Fauna			0.13 Bq (0.82 Bq/g)	4.0 Bq (1.6 Bq/g)	2.8 Bq (1.6 Bq/g)	0.52 Bq (0.72 Bq/g)	0.68 Bq (0.67 Bq/g)	9.5 Bq (5.1 Bg/g)	2.9 Bq (1.8 Bq/g)
Macrophytes			43 Bq (7.4 Bq/g)	34 Bq (4.1 Bq/g)	36 Bq (5.1 Bq/g)	43 Bq (4.4 Bq/g)	74 Bq (7.0 Bq/g)	120 Bq (7.6 Bq/g)	58 Bq (5.9 Bq/g)
Periphyton		14 Bq (89 Bq/g)	32 Bq (18 Bq/g)	13 Bq (86 Bq/g)	14 Bq (285 Bq/g)	24 Bq (24 Bq/g)	27 Bq (32 Bq/g)	21 Bq (58 Bq/g)	22 Bq (84 Bq/g)
Macrophyte Detritus			5.2 Bq (3.9 Bq/g)	5.8 Bq (3.5 Bq/g)	6.5 Bq (5.0 Bq/g)	3.0 Bq (1.0 Bq/g)	7.6 Bq (5.3 Bq/g)	17 Bq (2.4 Bq/g)	7.35 Bq (3.5 Bq/g)
Total		1200 Bq	1500 Bq	370 Bq	1200 Bq	1300 Bq	1600 Bq	1300 Bq	1200 Bq

XXX = Total activity in microcosm component
(XXX) = Activity per unit of microcosm component

TABLE 4-13

Thorium-228 Mass Balances for Littoral Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms						
			1	2	3	4	5	6	Mean
Water	1200 Bq (29.6 Bq/L)	0.62 Bq (0.015 Bq/L)	0.49 Bq (0.012 Bq/L)	0.338 Bq (0.008 Bq/L)	**? (L0.005 Bq/L)	0.49 Bq (0.012 Bq/L)	0.45 Bq (0.011 Bq/L)	0.41 Bq (0.010 Bq/L)	0.36 Bq (0.009 Bq/L)
Sediment (0-3 cm)		710 Bq (0.26 Bq/g)	600 Bq (0.220 Bq/g)	87 Bq *(0.032 Bq/g)	710 Bq (0.26 Bq/g)	710 Bq (0.26 Bq/g)	1400 Bq (0.50 Bq/g)	760 Bq (0.28 Bq/g)	710 Bq (0.36 Bq/g)
Sediment (3-8)		100 Bq (0.028 Bq/g)	96 Bq (0.024 Bq/g)	**? (L0.010 Bq/g)	100 Bq (0.025 Bq/g)	210 Bq (0.052 Bq/g)	110 Bq (0.027 Bq/g)	100 Bq (0.026 Bq/g)	100 Bq (0.027 Bq/g)
Suspended Material		No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	- -
Fauna			0.33 Bq (2.1 Bq/g)	0.67 Bq (0.27 Bq/g)	1.1 Bq (0.62 Bq/g)	0.28 Bq (0.39 Bq/g)	0.41 Bq (0.40 Bq/g)	1.1 Bq (0.59 Bq/g)	0.65 Bq (0.73 Bq/g)
Macrophytes			5.4 Bq (0.93 Bq/g)	6.3 Bq (0.76 Bq/g)	1.7 Bq (0.24 Bq/g)	3.2 Bq (0.33 Bq/g)	3.5 Bq (0.33 Bq/g)	12 Bq (0.77 Bq/g)	5 Bq (0.56 Bq/g)
Periphyton		3.00 Bq (20 Bq/g)	5.0 Bq (2.8 Bq/g)	0.49 Bq (3.3 Bq/g)	0.21 Bq (4.2 Bq/g)	2.7 Bq (2.7 Bq/g)	1.9 Bq (2.3 Bq/g)	0.43 Bq (1.2 Bq/g)	1.8 Bq (2.7 Bq/g)
Macrophyte Detritus			No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis
Total		810 Bq	700 Bq	95 Bq	810 Bq	930 Bq	1500 Bq	880 Bq	820 Bq

* Data not used to calculate mean
** = Equated to zero for calculation of mean
L = less than or equal to
XXX = Total activity in microcosm component
(XXX) = Activity per unit of microcosm component

TABLE 4-14

Lead-210 Mass Balances for Littoral Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms						
			1	2	3	4	5	6	Mean
Water	1500 Bq (37.0 Bq/L)	? (0.30 Bq/L)	15 Bq (0.37 Bq/L)	160 Bq (3.9 Bq/L)	21 Bq (0.50 Bq/L)	12 (0.30 Bq/L)	? (L0.30 Bq/L)	? (L0.300 Bq/L)	35 (0.80 Bq/L)
Sediment (0-3 cm)		930 Bq (0.34 Bq/g)	900 Bq (0.33 Bq/g)	*? *(L0.20 Bq/g)	870 Bq (0.32 Bq/g)	2100 Bq (0.78 Bq/g)	1700 Bq (0.64 Bq/g)	1100 Bq (0.40 Bq/g)	1100 Bq (0.49 Bq/g)
Sediment (3-8)		? (L0.20 Bq/g)	? (L0.20 Bq/g)	? (L0.20 Bq/g)	*1800 Bq *(0.45 Bq/g)	*4800 Bq *(1.2 Bq/g)	*5600 Bq *(1.4 Bq/g)	? (L0.20 Bq/g)	? (L0.200 Bq/g)
Suspended Material		? (L0.80 Bq/g)	? (L0.80 Bq/g)	? (L0.80 Bq/g)	? (L0.80 Bq/g)	? (L0.80 Bq/g)	? (L0.80 Bq/g)	? (L0.80 Bq/g)	? (L0.80 Bq/g)
Fauna			? (L1.0 Bq/g)	? (L1.0 Bq/g)	7.6 Bq (4.3 Bq/g)	2.2 Bq (3.1 Bq/g)	1.6 Bq (1.6 Bq/g)	1.9 Bq (1.0 Bq/g)	2.2 Bq (1.7 Bq/g)
Macrophytes			26 Bq (4.5 Bq/g)	27.4 Bq (3.30 Bq/g)	7.8 Bq (1.1 Bq/g)	22 Bq (2.3 Bq/g)	19 Bq (1.8 Bq/g)	64 Bq (4.0 Bq/g)	28 Bq (2.8 Bq/g)
Periphyton		21.0 Bq (138 Bq/g)	17 Bq (9.5 Bq/g)	1.20 Bq (8.04 Bq/g)	*12 Bq *(2 BqBq/g)	1.6 Bq (1.6 Bq/g)	4.8 Bq (5.8 Bq/g)	6.4 Bq (18 Bq/g)	6.2 Bq (8.6 Bq/g)
Macrophyte Detritus			2.9 Bq (2.2 Bq/g)	3.81 Bq (2.33 Bq/g)	1.6 Bq (1.2 Bq/g)	2.3 Bq (0.80 Bq/g)	4.5 Bq (3.1 Bq/g)	12 Bq (1.8 Bq/g)	4.5 Bq (1.9 Bq/g)
Total		950 Bq	960 Bq	190 Bq	2700 Bq	6700 Bq	7300 Bq	1200 Bq	1200 Bq

* Data not used to calculate mean
L = less than or equal to
XXX = Total activity in microcosm component
(XXX) = Activity per unit of microcosm component

TABLE 4-15

Polonium-210 Mass Balances for Littoral Microcosms

Microcosm Components	Initial Addition (Initial Concentration)	Control Microcosm	Experimental Microcosms						
			1	2	3	4	5	6	Mean
Water	1500 Bq (37.0 Bq/L)	18 Bq (0.43 Bq/L)	? (L0.30 Bq/L)	? (L0.30 Bq/L)	? (L0.30 Bq/L)	? (L0.30 Bq/L)	? (L0.30 Bq/L)	? (L0.30 Bq/L)	? (L0.30 Bq/L)
Sediment (0-3 cm)		1200 Bq (0.45 Bq/g)	1200 Bq (0.45 Bq/g)	*600 Bq *(0.22 Bq/g)	1400 Bq (0.53 Bq/g)	1300 Bq (0.48 Bq/g)	1700 Bq (0.62 Bq/g)	980 Bq (0.36 Bq/g)	1100 Bq (0.498 Bq/g)
Sediment (3-8)		640 Bq (0.160 Bq/g)	520 Bq (0.13 Bq/g)	280 Bq (0.07 Bq/g)	880 Bq (0.22 Bq/g)	480 Bq (0.12 Bq/g)	360 Bq (0.09 Bq/g)	360 Bq (0.09 Bq/g)	480 Bq (0.12 Bq/g)
Suspended Material		No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis
Fauna			0.97 Bq (6.1 Bq/g)	12 Bq (4.6 Bq/g)	7.7 Bq (4.3 Bq/g)	4.1 Bq (5.7 Bq/g)	5.4 Bq (5.3 Bq/g)	15 Bq (8.2 Bq/g)	7.5 Bq (5.7 Bq/g)
Macrophytes			15 Bq (2.6 Bq/g)	23 Bq (2.8 Bq/g)	11 Bq (1.6 Bq/g)	16 Bq (1.6 Bq/g)	16 Bq (1.5 Bq/g)	52 Bq (3.2 Bq/g)	22 Bq (2.2 Bq/g)
Periphyton		10 Bq (66 Bq/g)	11 Bq (6.4 Bq/g)	2.2 Bq (15 Bq/g)	1.7 Bq (34 Bq/g)	4.0 Bq (4.0 Bq/g)	4.6 Bq (5.6 Bq/g)	2.9 Bq (8.0 Bq/g)	4.4 Bq (12 Bq/g)
Macrophyte Detritus			No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis	No Analysis
Total		1900 Bq	1700 Bq	920 Bq	2300 Bq	1800 Bq	2100 Bq	1400 Bq	1600 Bq

* Data not used to calculate mean

L = Less than or equal to

XXX = Total activity in microcosm component

(XXX) = Activity per unit of microcosm component

The sediment data in Table 4-2 is given for the surface (0-3 cm) and deep (3 cm to microcosm bottom) fractions. Table 4-3 reports the analyses of the separate one centimetre sections of the surface fraction. The surface fraction of microcosm 2 exhibited unusually low values for all radionuclides in relation to the other five experimental microcosms and the control (Table 4-2). In addition, microcosms 3, 4 and 5) had larger activities of lead-210 in the deep sediment fraction than in the surface fraction. A review of analytical procedures and calculations resulting in these variations (in microcosms 2, 3, 4 and 5) did not reveal any satisfactory explanation. One possible explanation for some of the variability would be the lack of homogeneous sampling. Each one centimetre sediment fraction was a combination of three corresponding fractions from three different core samples taken at different locations in the microcosm. After mixing and drying approximately 10 g of sediment from each one centimetre section composite sample was taken and combined to form the 0-3 cm surface and 3 cm to bottom deep sediment fractions. Substantial spatial variation of radionuclide activity, as well as inadequate mixing during the preparation of composite samples may have contributed to the variations observed in microcosms 2, 3, 4 and 5.

Due to this variability, all radionuclide concentrations and activities for the surface fraction of microcosm 2 and the lead-210 activities for the deep fraction of microcosms 3, 4 and 5 were not used in the calculation of experimental microcosm averages.

Student's t-test (using a 0.05 level of significance) was used to determine if the control microcosm water and sediment radionuclide concentrations were significantly different from the range of radionuclide concentrations found in the water and sediment of the experimental microcosms after three months of littoral community growth.

432 MASS BALANCES

On average, 66% of the uranium and 68% of the thorium-228 were accounted for in their respective mass balances. The latter mass balance contained two components for which analyses were not conducted. On average, summing of the microcosm components for radium-226 accounted for 79% of the radium-226 activity added. On average, the microcosm components for lead-210 resulted in 73% of the activity initially added to the water. In the case of the lead-210 mass balance, three components (water, suspended material and deep fraction sediment) had activities below detection limits. The mass balance for polonium-210 was overestimated by 5% when the microcosm components were totalled.

Despite these differences the littoral microcosms did demonstrate:

- a significant decrease of the uranium concentration in the water of the experimental microcosms accompanied by a significant increase of uranium in the sediment;
- an increase of all radionuclide concentrations and activities in the sediment surface over the initial water concentration;
- a decrease of all radionuclide concentrations and activities with increased sediment depth;
- the presence of a positive relationship between uranium concentration and periphyton biomass;
- the presence of an inverse relationship between radium-226 and periphyton biomass;
- the presence of an inverse relationship between polonium-210 and the faunal biomass;

- the presence of inverse relationships between both uranium and radium-226 and the weight of suspended material in the water; and

- the concentration of radionuclides by periphyton, macrophytes, fauna, detritus and suspended material.

Results of the radionuclide distributions in the littoral microcosms will be discussed for each individual radionuclide in the following sections.

433 URANIUM

.1 Water

The uranium water concentrations in the experimental microcosms ranged from 42 to 230 ug/L and averaged 117 ug/L. The control microcosm concentration (415 ug/L) was significantly greater (at the 0.05 level) than the experimental concentrations. The presence of the littoral community apparently had an effect in the removal of uranium from the water.

.2 Sediment

The concentrations of uranium in the surface fraction (0-3 cm) of the sediment from the experimental microcosms ranged from 4.7 to 5.8 ug/g and averaged 5.3 ug/g. The concentration of uranium in the surface fraction of the control microcosm (3.5 ug/g) was significantly lower (at the 0.05 level) than the experimental microcosms. Thus, the presence of a littoral community apparently had an effect in increasing the sediment concentrations of uranium in the surface fraction.

The deep fraction sediment (3 cm to microcosm bottom) uranium concentrations ranged from 1.5 to 2.2 ug/g and averaged 1.8 ug/g. The

control microcosm deep fraction (1.8 ug/g) was not significantly different from the experimental microcosms at either the 0.05 or 0.1 level.

Uranium analysis of the experimental microcosm one centimetre sections (Table 4-3) showed the following ranges and averages:

- o 0-1 cm section, 6.0 to 21 ug/g, 10 ug/g;
- o 1-2 cm section, 2.0 to 11 ug/g, 6.1 ug/g; and
- o 2-3 cm section, 1.1 to 10 ug/g, 3.2 ug/g.

Although the general tendency was for the concentration of uranium to decrease with increasing sediment depth (as demonstrated by the average concentrations above), microcosms 3 and 4 had higher concentrations on the lowest section. A possible explanation for this inversion was discussed earlier in Section 4.3.

The control microcosm one centimetre sections had the following uranium concentrations:

- o 0-1 cm section, 6.6 ug/g;
- o 1-2 cm section, 4.7 ug/g; and
- o 2-3 cm section, 3.2 ug/g.

The concentrations of uranium in the control microcosm one centimetre sections were not significantly different from the corresponding sections in the experimental microcosms.

.3 Macrophytes

Uranium concentrations associated with the aquatic macrophytes ranged from 7.60 to 32.1 ug/g and averaged 15.1 ug/g. The macrophytes contained, on average, 15 times the initial water uranium concentration. Most of this may have been associated with periphytic growth on the leaf surfaces (see Table 4-7).

.4 Fauna

The concentrations of uranium associated with the fauna ranged from below detection limits (less than or equal to 0.50) to 3.97 ug/g and averaged 3.56 ug/g. On average, the fauna contained approximately three times of initial concentration of uranium in the water.

.5 Periphyton

The concentrations of uranium associated with the periphyton ranged from 61 to 100 ug/g and averaged 77 ug/g. The concentration of uranium associated with the periphyton in the control microcosm (110 ug/g) was not significantly different from the experimental microcosms. The periphyton from the experimental microcosms contained, on average, 80 times the uranium of the initial water concentration.

.6 Macrophyte Detritus

Uranium concentrations associated with the macrophyte detritus ranged from 15.3 to 140 ug/g and averaged 95.2 ug/g. The macrophyte detritus contained, on average, 95 times the initial water concentration of uranium.

.7 Suspended Material

The concentration of uranium associated with the suspended material ranged from 4.0 to 67 ug/g and averaged 21 ug/g. An inverse relationshp was observed for uranium concentration and suspended material from two litres of water in the experimental and control microcosms except microcosm 5 (the lowest concentration of uranium). Linear regression analysis of data from the microcosms (exclusive of microcosm 5) demonstrated a regression coefficient of -0.894 and defined the relationship by:

$$Y = -1,138.86X + 66.126$$

where Y is the concentration of uranium (ug/g) associated with the dry weight of suspended material (X).

The suspended material contained, on average, 25 times the initial water uranium concentration.

.8 Distribution of Uranium in Microcosms

The sediment accounted for 75% of the uranium in the experimental microcosms (Table 4-11). The surface fraction (0-3 cm) accounted for 48% and the deep sediment fraction accounted for 27% of the total microcosm uranium. The water accounted for 18% of the uranium in the experimental microcosms. The remaining components (i.e. suspended material, fauna, macrophytes, periphyton and detritus) together accounted for approximately 7% of the microcosm uranium. Although the components accounted for an extremely small amount of the total microcosm uranium, some of them had extremely high concentrations of uranium. For example, detritus and periphyton had average uranium concentrations of 95.2 and 77 ug/g, respectively.

By contrast, 50% of the control microcosm uranium remained in the water. An almost equal amount (49%) was accounted for by the sediment (surface fraction, 28%; deep fraction, 21%). The small amount of periphyton in the control microcosm (17 ug/g) accounted for less than 1% of the microcosm uranium.

434 RADIUM-226

.1 Water

The activities of radium-226 ranged from 0.16 to 0.38 Bq/L and averaged 0.24 Bq/L. The control microcosm activity (0.45 Bq/L), although higher than the experimental microcosms, was not significantly different from them at the 0.05 level. when tested at the 0.1 level, however, the difference was significant.

.2 Sediment

The activities of radium-226 in the surface fraction of the sediment from the experimental microcosms ranged from 0.31 to 0.47 Bq/g and averaged 0.38 Bq/g. The activity of radium-226 in the surface fraction of the control microcosm (0.36 Bq/g) was not significantly different from the range of activities in the surface fractions of the experimental microcosms.

The deep fraction sediment radium-226 activities ranged from 0.021 to 0.090 Bq/g and averaged 0.061 Bq/g. The control microcosm deep fraction (0.043 Bq/g) was not significantly different from the experimental microcosms.

Radium-226 activities of the experimental microcosm one centimetre sections (Table 4-3) showed the following ranges and averages:

- o 0-1 cm section, 0.28 to 1.4 Bq/g, 0.64 Bq/g;
- o 1-2 cm section, 0.09 to 0.54 Bq/g, 0.41 Bq/g; and
- o 2-3 cm section, 0.11 to 0.51 Bq/g, 0.32 Bq/g.

The general tendency of decreasing radium-226 concentrations with depth was observed in the experimental microcosms. There were a few instances where a lower section had a slightly higher concentration than

the section immediately above it. These differences, however, were not large and could have been caused by analytical variability. As well, variation within the individual core sections used to make the composite might also have contributed to the higher activities at lower depths.

The control microcosm one centimetre sections had the following radium-226 activities:

- o 0-1 cm section, 0.60 Bq/g;
- o 1-2 cm section, 0.32 Bq/g; and
- o 2-3 cm section, 0.12 Bq/g.

The activities of radium-226 in the control microcosm one centimetre sections were not significantly different from the corresponding sections in the experimental microcosms.

.3 Macrophytes

Radium-226 activities associated with the aquatic macrophytes ranged from 4.4 to 7.6 Bq/g and averaged 5.9 Bq/g. The macrophytes contained, on average, 160 times the initial water radium-226 activity.

.4 Fauna

The activities of radium-226 associated with the fauna ranged from 0.67 to 5.1 Bq/g and averaged 1.8 Bq/g. The fauna contained, on average, approximately 45 times the initial activity in the water.

.5 Periphyton

The activities of radium-226 associated with the periphyton ranged from 18 to 285 Bq/g and averaged 84 Bq/g. The activity of radium-226 associated with the periphyton in the control microcosm (89 Bq/g) was not significantly different from the activities in the

experimental microcosms. The periphyton from the experimental microcosms contained, on average, 2300 times the radium-226 of the initial water activity.

An inverse relationship between the radium-226 activity and the experimental periphyton biomass was observed. Linear regression analysis demonstrated a regression coefficient of -0.6331. Examination of the paired data leading to this regression coefficient indicated that microcosm 3 had an activity (285 Bq/g) much higher than would be expected from the trend exhibited by the other microcosms. Removal of microcosm 3 from the data set resulted in a regression coefficient of -0.899. This relationship was defined by the equation:

$$Y = -44.8187X + 83.2158$$

where Y is the activity (Bq/g) of radium-226 associated with the grams dry weight of periphyton (X).

6. Macrophyte Detritus

Radium-226 activities associated with the macrophyte detritus ranged from 1.0 to 5.3 Bq/g and averaged 3.5 Bq/g. The macrophyte detritus contained, on average, 95 times the initial water activity.

.7 Suspended Material

The activities of radium-226 associated with the suspended material ranged from 0.90 to 19 Bq/g and averaged 5.7 Bq/g. An inverse relationship was observed for radium-226 activities and suspended material in the experimental microcosms. This relationship did not include microcosms 1 and 3 which contained the highest concentrations of suspended solids. Without microcosms 1 and 3, the linear regression analysis demonstrated a regression coefficient of -0.846 and defined the relationship by:

$$Y = -353.144X + 18.546$$

where Y is the activity of radium-226 (Bq/g) associated with the grams dry weight of suspended material (X).

The suspended material contained, on average, 150 times the initial water radium-226 activity.

.8 Distribution of Radium-226 in Microcosms

The sediment accounted for the majority (89%) of radium-226 activity in the littoral microcosms (Table 4-12). The surface fraction (0-3 cm) accounted for 72% and the deep fraction (greater than 3 cm) accounted for 18% of the total microcosm radium-226 activity.

Although having less than one tenth the weight of the macrophytes, the periphyton (average 84 Bq/g) accounted for about 7% of the total microcosm radium-226 activity whereas the macrophytes accounted for 5%. The remainder of the components each accounted for less than one percent of the total microcosm radium-226 activity.

Like the experimental microcosms, the control sediment accounted for the majority of radium-226 activity (96%). The surface fraction (0-3 cm) accounted for 82% and the deep fraction (greater than 3 cm) accounted for 14%. The periphyton in the control, although smaller in weight than the average experimental microcosm value, accumulated radium-226 to about the same extent (i.e. 89 Bq/g). This high activity allowed for this component to account for just over one percent of the total control microcosm radium-226 activity. The water component in the control (1.6%) accounted for about double the activity reported for the average of the experimental microcosms.

435 THORIUM-228

.1 Water

The activities of thorium-228 in the experimental microcosms ranged from below detection limits (less than or equal to 0.005) to 0.012 Bq/L and averaged 0.009 Bq/L. The microcosm control (0.015 Bq/L) was not significantly different from the experimental activities.

.2 Sediment

The activities of thorium-228 in the surface sediment fractions from the experimental microcosms ranged from 0.22 to 0.50 Bq/g and averaged 0.30 Bq/g. The activity of thorium-228 in the surface fraction of the control microcosm (0.26 Bq/g) was not significantly different from the range of activities in the surface fractions of the experimental microcosms.

The deep sediment fraction thorium-228 activities ranged from below detection limits (less than 0.010) to 0.052 Bq/g and averaged 0.026 Bq/g. The control microcosm deep fraction (0.028 Bq/g) was not significantly different from the experimental microcosms.

An analysis for thorium-228 was not conducted on the one centimetre sections of the surface fraction of sediments.

.3 Macrophytes

Thorium-228 activities associated with the aquatic macrophytes ranged from 0.24 to 0.93 Bq/g and averaged 0.56 Bq/g. The aquatic macrophytes contained, on average, 20 times the initial water thorium-228 activity.

.4 Fauna

The activities of thorium-228 associated with the fauna ranged from 0.27 Bq/g to 2.1 Bq/g and averaged 0.73 Bq/g. The fauna contained, on average, approximately 25 times the initial water activity.

.5 Periphyton

The activities of thorium-228 associated with the periphyton ranged from 1.2 to 4.2 Bq/g, and averaged 2.7 Bq/g. The activity of thorium-228 associated with the periphyton of the control microcosm (20 Bq/g) was significantly higher than the experimental microcosms. The meaning of this difference is obscured by the differences in growth patterns of the periphyton between the control and experimental microcosms as discussed in Section 4.2. The periphyton of the experimental microcosms contained, on average, 90 times the initial water activity.

.6 Macrophyte Detritus

Thorium-228 analysis was not conducted on macrophyte detritus so that more effort could be directed toward increased sediment analyses.

.7 Suspended Material

Thorium-228 analysis was not conducted on suspended material in so that more effort could be directed toward increased sediment analyses.

.8 Distribution of Thorium-228 in Microcosms

The sediment accounted for the majority (99%) of the thorium-228 activity in the experimental microcosms, with the surface fraction (0-3 cm) accounting for 87% of the total microcosm thorium-228 activity (Table 4-13). The highest thorium-228 activity was associated with the periphyton (average 2.7 Bq/g) but this component together with

the fauna (average 0.73 Bq/g), macrophytes (average 0.56 Bq/g) and water (average 0.009 Bq/L) accounted for only 1% of the total microcosm thorium-228 activity recovered in the experimental microcosms.

Like the experimental microcosms, 99% of the thorium activity in the control microcosms was associated with the sediment. The surface fraction accounted for 88% of the total recovered thorium-228 activity in the microcosm. Although the control microcosm periphyton (20 Bq/g) had seven times the average activity of the experimental microcosms periphyton, it, along with the control water (0.015 Bq/L) accounted for only 1% of the thorium-228 activity in the control microcosm.

436 LEAD-210

.1 Water

The activities of lead-210 in the experimental microcosms ranged from below detection limits (less than or equal to 0.3) to 3.9 Bq/L and averaged 0.80 Bq/L. The control microcosm lead-210 activity was also below detection limits. As three of the six experimental microcosms were also below detection limits it was assumed that no difference existed between the experimental and control microcosms.

.2 Sediment

The activities of lead-210 in the surface fraction of sediment from the experimental microcosms ranged from 0.32 to 0.78 Bq/g and averaged 0.49 Bq/g. The activity of lead-210 in the surface fraction of the control microcosm (0.34 Bq/g) was not significantly different from the range of activities in the surface fractions of the experimental microcosms.

The deep fraction sediment lead-210 activities ranged from below detection limits (less than or equal to 0.2) to 1.40 Bq/g. However, microcosms 3, 4 and 5 had higher concentrations in the deep fraction than the surface fraction. The remaining microcosms (including the control) had lead-210 activities below detection limits. As explained earlier (Section 4.3), the activities for lead-210 in the deep fraction for microcosms 3, 4 and 5 were not used in the calculation of experimental microcosm averages.

The lead-210 activities of the experimental microcosm one centimetre sections (Table 4-3) exhibited the following ranges and averages:

- o 0-1 cm section: less than or equal to 0.2 to 0.96 Bq/g, 0.51 Bq/g;
- o 1-2 cm section: less than or equal to 0.2 to 0.36 Bq/g, 0.23 Bq/g; and
- o 2-3 cm section: less than or equal to 0.2 to 0.25 Bq/g, 0.16 Bq/g.

The general tendency of decreasing lead-210 activities was observed with depth. Where increases in lower sediment sections did occur (microcosm 3), the increase was small (i.e. 0.25 to 0.31 Bq/g). Lead-210 was below detection limits in all three of the one centimetre core sections in microcosm 2, lending support to the observation made in Table 4-2 concerning lower than expected activities in the surface fraction for all radionuclides.

The control microcosm one centimetre sections had the following lead-210 activities:

- o 0-1 cm section, 0.73 Bq/g;
- o 1-2 cm section, 0.22 Bq/g; and
- o 2-3 cm section, less than or equal to 0.2 Bq/g.

The activities of lead-210 in the control microcosm one centimetre sections were not significantly different from the corresponding sections in the experimental microcosms.

.3 Macrophytes

Lead-210 activities ranged from 1.1 to 4.5 Bq/g and averaged 2.8 Bq/g. The aquatic macrophytes contained, on average, 75 times the initial water lead-210 activity.

.4 Fauna

The activities of lead-210 associated with the fauna ranged from below detection limits (less than or equal to 1.0) to 4.3 Bq/g. The fauna contained, on average, approximately 45 times the initial water activity.

.5 Periphyton

The activities of lead-210 associated with the periphyton ranged from 1.6 to 237 Bq/g and averaged 8.5 Bq/g (excluding the 237 value). The activity of lead-210 in the control microcosm (138 Bq/g) would be significantly different from the experimental microcosms if microcosm 3 (237 Bq/g) is removed from consideration. However, the meaning of this difference is obscure considering the different growth patterns exhibited by the experimental and control periphyton (as discussed in Section 4.2). The experimental microcosm periphyton exhibited, on average, 1,300 times the initial activity of lead-210 in the water.

.6 Macrophyte Detritus

Lead-210 activities associated with the macrophyte detritus ranged from 0.80 to 3.1 Bq/g and averaged 1.9 Bq/g. The macrophyte detritus contained, on average, 50 times the initial water activity of lead-210.

.7 Suspended Material

Lead-210 activities were below detection limits (less than or equal to 0.8 Bq/g) in all microcosms. If the maximum activity of lead-210 in the suspended material was 0.8 Bq/g, this would be approximately 20 times the initial lead-210 water activity.

.8 Distribution of Lead-210 in Microcosms

The sediment accounted for the majority (92%) of the total lead-210 activity in the littoral microcosms (Table 4-14). Lead-210 could not be detected in the sediment deep fraction (3 cm and deeper), therefore the surface fraction (0.41 Bq/g) is assumed to be the component having the largest fraction of the lead-210 activity. The highest individual activity of lead-210 within the microcosms was associated with the periphyton (average 8.6 Bq/g) which accounted for 0.5% of the total microcosm lead-210 activity. Macrophytes and fauna accounted for 2% and 0.2%, respectively, of the total microcosm lead-210 activity.

Lead-210 activity could not be detected in the water or suspended material of the experimental microcosms.

Like the experimental microcosms, lead-210 activity could not be detected in either the water or the sediment deep fraction of the control microcosm. Also, the surface fraction of the sediment (0-3 cm) accounted for 98% of the total microcosm lead-210 activity. In comparison to the experimental microcosms, the control periphyton had almost

three times the lead-210 activity allowing it to account for approximately 2% of the control microcosm lead-210 activity.

437 POLONIUM-210

.1 Water

The activities of polonium-210 in the experimental microcosms were all below detection limits (less than or equal to 0.30 Bq/L). The significance of the control microcosm activity (0.43 Bq/L) could not be determined.

.2 Sediment

The activities of polonium-210 in the surface sediment fractions from the experimental microcosms ranged from 0.36 to 0.53 Bq/g and averaged 0.49 Bq/g. The control microcosm surface fraction (0.45 Bq/g) was not significantly different from the range of activities in the experimental microcosms.

The deep sediment fraction polonium-210 activities ranged from 0.07 to 0.22 Bq/g and averaged 0.12 Bq/g. The control microcosm deep fraction (0.16 Bq/g) was not significantly different from the range of activities in the experimental microcosms.

The one centimetre sections of the sediment surface fraction were not analyzed for polonium-210.

.3 Macrophytes

Polonium-210 activities ranged from 1.5 to 3.2 Bq/g and averaged 2.2 Bq/g. The aquatic macrophytes contained, on average, 60 times the initial water polonium-210 activity.

.4 Fauna

The activities of polonium-210 associated with the fauna ranged from 4.3 to 8.2 Bq/g and averaged 5.7 Bq/g. An inverse relationship was observed between the polonium-210 activity and fauna biomass. Linear regression analysis demonstrated a regression coefficient of -0.993 for the two variables and defined the relationship by:

$$Y = -1.1351X + 64120$$

where Y is the activity of polonium-210 (Bq/g) associated with the grams dry weight of the fauna (X).

To obtain this relationship, the fauna biomass of microcosms 2 and 6 had to be dropped from the data set. The concentrations of polonium-210 in the fauna of these microcosms were much higher than would be expected from the trend established by the other microcosms. The apparent reason for this difference is that microcosms 2 and 6 were dominated by snails (molluscs). Heyrand and Cherry (1979) observed a strong discrimination (prefered uptake) for polonium-210 in the hepato-pancreas of marine molusca. This very same preference could have been at work in the snail populations of microcosms 2 and 6.

.5 Periphyton

The activities of polonium-210 associated with the periphyton ranged from 4.0 to 34 Bq/g and averaged 12 Bq/g. The activity of the polonium-210 associated with the periphyton of the control microcosm (66 Bq/g) was significantly different from the experimental microcosms. The meaning of this difference is obscured by the difference in growth patterns of the periphyton between the control and experimental microcosm as discussed earlier (Section 4.2). The periphyton from the experimental microcosms contained, on average, 300 times the initial water activity.

.6 Macrophyte Detritus

Polonium-210 analysis was not conducted on detritus in order that more effort could be directed toward an increased number of sediment analyses.

.7 Suspended Material

Polonium-210 analysis was not conducted on suspended material in order that more effort could be directed toward an increased number of sediment analyses.

.8 Distribution of Polonium-210 in Microcosms

The sediment accounted for the majority (99%) of the polonium-210 in the littoral microcosms (Table 4-15). The sediment surface fraction (0.49 Bq/g) accounted for 69% of the polonium-210 activity recovered in the microcosms while the deep fraction (0.12 Bq/g) accounted for 30%. The highest polonium-210 activity was associated with the periphyton (12 Bq/g) but this component accounted for only 0.3% of the recovered polonium-210 activity. Polonium-210 analysis was not conducted on the detritus or suspended material. Polonium-210 activity could not be detected in the water (less than or equal to 0.3 Bq/L).

By contrast, polonium-210 was detected in the control microcosm water (0.43 Bq/L) but accounted for less than 1% of the total polonium-210 activity. Like the experimental microcosms, the majority (97%) of the polonium-210 activity was associated with the sediment. The surface fraction (0-3 cm) accounted for most of the total activity in the microcosm (63%). The control periphyton had a polonium-210 activity (66 Bq/g) approximately 5 times the periphyton polonium-210 activity of the experimental microcosms, but accounted for less than 1% of the total control microcosm polonium-210 activity.

438 COMPARISON OF RADIONUCLIDES

Of the five radionuclides introduced into the microcosms all showed large decreases in the water. These reductions resulted from the interaction of the following factors:

- o uptake (adsorption or absorption) by fauna;
- o uptake (adsorption or absorption) by the flora;
- o adsorption to suspended material;
- o adsorption to the sediment; and
- o adsorption to the microcosm walls.

The summation of these factors resulted in the removal from the water of the following percentages of the radionuclides in the experimental microcosms.

- o Uranium: 88.3%;
- o Radium-226: 93.6%;
- o Thorium-228: 99.97%;
- o Lead-210: greater than 98.6%; and
- o Polonium-210: greater than 99.2%.

Uranium and radium-226 demonstrated a significant reduction in water concentration between the experimental and control microcosms. Therefore it must be concluded that the large decreases observed in the other radionuclides were due to factors other than the presence of a littoral community.

All radionuclides were concentrated in the surface sediment fraction (0-3 cm) (relative to the initial water concentration) by the following factors:

- o Uranium: 5X;
- o Radium-226: 10X;

- Thorium-228: 10X;
- Lead-210: 10X; and
- Polonium-210: 10X.

Although there was extreme variability in the activities of all radionuclides in the periphyton component, radium-226 was accumulated (relative to the amount introduced) to the greatest extent (2,300X) and uranium the least (60X). The remaining radionuclides were concentrated by the following relative factors:

- Thorium-228: 90X;
- Lead-210: 1,300X; and
- Polonium-210: 300X.

Although the concentrations and activities of all radionuclides associated with the fauna varied over a wide range, polonium-210 was concentrated to the greatest extent (150X) and uranium to the least (3X), relative to the initial water concentration. The remaining radionuclides were concentrated by the following factors:

- Radium-226: 45X;
- Thorium-228: 25X; and
- Lead-210: 45X.

Relative to the initial water concentration, aquatic macrophytes were observed to concentrate radium-226 to the greatest extent (160X) and uranium the least (15X). The remaining radionuclides were concentrated by the following relative factors:

- Thorium-228: 20X;
- Lead-210: 75X; and
- Polonium-210: 60X.

The suspended material in the littoral microcosms accumulated radium-226 to a greater extent (150X) than uranium (25X), relative to the initial water concentration. The lead-210 associated with the suspended material was below detection limits (i.e. less than or equal to 0.800 Bg/g). Suspended material was not analyzed for thorium-228 or polonium-210.

Relative to the initial water concentration, the macrophyte detritus concentrated uranium and radium-226 by 95X. The lead-210 concentration of the macrophyte detritus was 50 times the initial water concentration.

Of all the microcosm components analyzed, radium-226 reached its highest activity (relative to the other components) in the periphyton. Uranium was more concentrated in the macrophyte detritus than any other microcosm component. Polonium-210 seemed to have a greater affinity for the fauna than other microcosm components. Lead-210 had its greatest affinity for the periphyton compared with other microcosm components.

Thorium-228, with its reputation for extensive adsorption to surfaces, was concentrated to the greatest degree in the periphyton component. This may be due to the larger surface area offered by this component compared with other microcosm components.

Both uranium concentrations and radium-226 activities were inversely correlated with the weight of suspended material in the littoral microcosms. Although both uranium and radium-226 are known to be taken up (by adsorption and absorption) by unicellular algae, a well defined reason for these relationships was not found. Uranium concentrations and radium-226 activities were also observed to be correlated with periphyton dry weight. However, in this case, uranium concentrations were positively correlated and radium-226 activities were negatively correlated. An explanation for these relationships was not found. The

pattern of burial and mixing within the activate sediment layer as observed for cesium-37 in experiments by Fisher et al. (1980) and Krezoski and Robbins (1985). The ultimate burial of thorium-228 contaminated sediment depends to a large degree upon local sedimentation rates and the density of conveyor-belt deposit feeders. The lower the sediment rate, the more the active sediment layer is mixed and the smaller the chances are for the eventual deposition of thorium-228 below the zone of active feeding and its ultimate burial.

534 LEAD-210

Surface adsorption of naturally occurring lead-210 by both inorganic and organic particulate material and its subsequent incorporation into accumulating sediments is the basis for a geological clock for establishing the chronology of recent sediments (Durham and Joshi 1981). Deposition of lead-210 derived from uranium mining will be expected to follow the same route and become mixed with the sediment by bioturbation processes in a manner similar to thorium-228.

535 POLONIUM-210

Like lead-210, polonium-210 has been found to be removed from water by surface adsorption. An additional pathway which is important for removal of polonium-210 from ocean surface waters is the phytoplankton-zooplankton-fecal pellet pathway. This same mechanism may be responsible for the removal of polonium-210 from the limnetic zone of lakes. If this is the case, fecal pellet membrane deterioration may only begin after contact with the sediment surface microbial community. The resulting mixing and redistribution of the pellet contents may proceed in the same manner as lead-210 except for one factor. In the present study, benthic organisms in the littoral and profundal microcosms were found to

work of Heyrand and Cherry (1979) described a strong discrimination for polonium-210 by marine molluscs. It may be that freshwater fauna also exhibit this discrimination. With small quantities of polonium-210 available to the fauna, the small faunal densities (i.e. smaller weights) could have more polonium-210 per unit weight available than larger faunal densities, possibly explaining this inverse relationship.

Figure 4-2 is a graphic representation of the distribution of radionuclides in the control and experimental littoral microcosms.

439 SUMMARY OF FINDINGS

Based on the difference between the uranium concentrations of the water in the control and experimental microcosms, the littoral community has a significant effect on reducing the concentration of uranium in the water. This same difference was observed for radium-226 activities. The decreased concentration of uranium in the water was accompanied by a significant increase of uranium in the surface sediment fraction (0-3 cm). There was no comparable increase in the radium-226 acitivity of the surface sediment fraction.

Although the remaining radionuclides were removed from the water of the microcosms to a greater extent than uranium, no significant difference could be demonstrated between control (no littoral community) and the experimental (littoral community) microcosms.

In addition to these conclusions, the littoral microcosms also demonstrated:

- the highest accumulation of radium-226 in the periphyton component compared to all other components;
- the highest accumulation of polonium-210 in the fauna component compared to all other components;

accumulate polonium-210 to a far greater extent than lead-210. Thus, epibenthic organisms may retain a portion of the polonium-210 and make it unavailable for sediment mixing by the organisms responsible for bioturbation.

FIGURE 4 - 2

RADIONUCLIDE DISTRIBUTION IN CONTROL AND EXPERIMENTAL LITTORAL MICROCOSMS

PART 6

SUMMARY

- the highest accumulation of uranium in the macrophyte detritus compared to all other components;

- the highest accumulation of lead-210 in the periphyton compared with other components,

- a negative regression between uranium concentrations and the associated suspended material dry weight;

- negative regressions between radium-226 activity and the dry weight of periphyton and suspended material; and

- a negative regression between polonium-210 and the dry weight of fauna.

Firm explanations for the relationships demonstrated between radionuclide concentrations or activities and the weight of the microcosm components could not be found.

PART 6 - SUMMARY

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PART 5

BENTHIC BIOTURBATION MICROCOSMS

PART 5 - BENTHIC BIOTURBATION MICROCOSMS

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5.0 BENTHIC BIOTURBATION MICROCOSMS

5.1 INTRODUCTION

Monenco's proposal to the National Uranium Tailings Program stated that an initial literature review would be conducted to determine the amounts of information available in published studies demonstrating:

- the removal of radionuclides from water by a pelagic or limnetic community;
- the removal of radionuclides from water by a profundal community;
- the removal of radionuclides from water by a littoral community; and
- the redistribution of sediment associated radionuclides by zoobenthic organisms.

Information concerning limnetic, profundal and littoral communities and radionuclide removal from the water was not found. As a result, Monenco constructed and maintained the abovementioned types of microcosms to determine the role of lacustrine organisms in the removal of uranium, radium-226, thorium-228, lead-210, and polonium-210 from the water.

The results of the literature review concerning the redistribution of sediment-associated radionuclides by zoobenthic organisms is presented below.

5.2 RESULTS OF LITERATURE REVIEW

Monenco reviewed the publish literature concerned with the redistribution of radionuclides within active sediment layers by zoobenthic organisms. The work of Robbins et al. (1977, 1979) firmly established the role of benthic invertebrates such as Tubifex tubifex and Pontopereia hoyi in mixing of radionuclide contaminated sediment layers with uncontaminated sediment.

A review of the vertical mixing of lake sediments (bioturbation) was given by Fisher et al. (1980). Their laboratory microcosm study involved the migration of a ^{137}Cs labeled sediment, deposited in a marker horizon, by the activity of tubificid oligochaetes. The marker horizon was deposited at depths of 0 (i.e. surface), 2, 4 and 8 cm in separate microcosms. In the microcosms containing the marker horizon at the surface, the ^{137}Cs activity moved downward at a constant rate until it reached a depth of approximately 7 cm. Below this point, the rate decreased markedly and approached zero at a depth of approximately 8.5 cm. Labelled sediment below the surface-water interface was continuously returned to the sediment-water interface from the 6-8 cm depth. Less labelled material was transferred to the surface sediments from depths less than 6-8 cm. The bulk of feeding activity of the oligochaetes in the laboratory microcosm (which determined the amount of material returned to sediment surface) was confined to an interval of approximately 6 to 9 cm in depth. At the termination of the experiment with marker horizon originating at the surface (120 days), the ^{137}Cs activity maximum had moved to a depth of 7.7 cm in the microcosms. With a population density of approximately 100,000 individuals/m^2, the downward velocity of the marker horizon due to the tubificid feeding was calculated to be 0.12±0.02 cm/day. This velocity corresponds to a mass flux of 25.9 g of dry sediment/cm^2/day.

In preparing a mathematical model of sediment mixing by tubificids, Fisher et al. (1980) assumed that the vertical velocity depended on the feeding rate and that the marker horizon descended uniformly (i.e. did not broaden during descent). Although, the resulting equation predicted the maximum depth to which radioactive marker horizon descended, it did not adequately predict the activity at any depth and time. To determine this parameter (i.e. activity at any depth and time) it was necessary to include in the model:

- a diffusion term to account for non-homogenous subduction;
- a more accurate description of the depth dependence of feeding rate;
- the assumption that the depth dependence of feeding was a linear function of depth for small depths, but approximated a Gaussian distribution near the zone of maximum feeding;
- the assumption that the shape of the feeding function near the zone of maximum feeding was constant in time; and
- the assumption that one-third of the sediment was not ingested by the feeding worms.

When these terms and assumptions were placed in the mathematical model, the calculated activity of the ^{137}Cs at any given depth and time was in good agreement with the experimental observations.

A review of the literature concerning depth distribution of tubificid feeding and burrowing activities by Fisher et al. (1980) implied that the depth of maximum tubificid feeding activity corresponded to the depth of peak tubificid abundance. However, calculations based on available data in the literature demonstrated that although 70% of the tubificid population was confined to the upper 3 cm of sediment, the zone

of maximum feeding occurred between 2 and 7 cm. This was in general agreement with the radiotracer experiments described by Fisher et al. (1980).

The depth and rate of maximum feeding of tubificids in nature may be expected to vary with:

- o the distribution of the tubificid lengths in the population;
- o the species composition of the population;
- o temperature;
- o sediment type;
- o dissolved oxygen; and
- o interactions with other benthic organisms (Fisher et al. 1980).

In addition to the above factors, the density and distribution of the tubificid populations will also influence the degree of bioturbation occurring in a lake sediment.

Taken alone, the reworking of lake sediments is not particularly meaningful unless compared to local sedimentation rates. When this latter factor is determined, it may be that zoobenthic populations of burrowing worms cause significant mixing of the surficial sediments to a depth of 6 to 8 cm.

Additional work with the ^{137}Cs marker horizon and ^{22}Na (a radionuclide weakly adorbed to sediments) demonstrated that the oligochaete Stylodrilus heringianus (at a population density of 6.7×10^4 individuals/m^2) caused a downward movement of 0.12 cm/day of the Cs-137 radiolabelled sediment to a depth of 4-6 cm. In two replicate cells with the amphipod Pontoporeia hoyi (density: $4.7 \times 10^3/m^2$) the diffusion coefficient of radiolabelled sediment was $1.43 \pm 0.25 \times 10^{-5}$ cm^2/s. No significant movement of the ^{137}Cs radiolabelled substrate was observed in laboratory microcosms containing the blood worm Chironomus tentans (density: $4.0 \times 10^3/m^2$) or the clams Pisidium sp. (density 4.0 x

$10^{-3}/m^2$) and Sphaerium sp. (density: $2.7 \times 10^3/m^2$). Thus, some zoobenthic organisms do not contribute to the mixing of sediments (Krezoski and Robbins 1981).

Recent work conducted by Krezoski and Robbins (1985) involved the movement of ^{137}Cs labelled sediment layers (approximately 0.5 mm thick) placed at 10 mm intervals in a sediment column microcosm of 110 mm depth. The organism used in these studies was Stylodrilus heringianus. The authors found that the relationship between feeding distribution (labelled layer removal rate) and velocity distribution (labelled layer burial rate) for S. heringianus could be described in terms of an advection-diffusion model which accounted for depth-dependent porosity changes. The model indicated that the transfer of ^{137}Cs occurred 1.67 times faster (as the result of size-selective feeding) than mass transfer of sediment. This indicates the importance of this type of species in contaminant diagenesis.

The same type of sediment mixing by oligochaetes (primarily by the smaller oligochaete Limnodrilus hoffmeisteri) was observed by Karickhoff and Morris (1985) in their study of organic pollutant transport in bottom sediments of laboratory microcosms.

A mathematical model for particle-selective transport of tracers in sediments with conveyor-belt deposit feeders (also known as vertically oriented, deposit feeding macrobenthos) was constructed by Robbins (1985). The model provided for the quantification of the effects of particle-selective, conveyor-belt deposit feeders in a two-phase system of sediments where radionuclide reactions are limited to simple linear adsorption to sediments and radioactive decay. The data used to generate and confirm this model was supplied by laboratory microcosms. Whether or not this model will give meaningful predications in the world outside the laboratory remains to be determined.

It is clear from these studies that sediment reworking by vertically oriented, deposit feeding macrobenthos results in subduction and mixing of the active sediment layer. A layer of sediment containing radionuclides above a zone of maximum feeding would move down as a reasonably discrete unit. Upon entering the zone of maximum feeding, the downward movement of the layer abruptly slows and a substantial flux of radionuclides from that layer may be transferred to the sediment water interface. As sediment working continues, the discrete layer of radionuclide contaminated sediment is mixed throughout the active layer. The rate at which mixing occurs depends on the population density of the macrobenthos, the species composition, temperature, sediment type, dissolved oxygen, and interactions with other benthic or profunal organisms.

Based on the information in the literature Monenco could not add substantially to the knowledge concerning zoobenthic redistribution of radionuclides by constructing and operating a microcosm. Rather than build benthic bioturbation microcosms. Monenco increased the replication of the profundal and littoral microcosms from that originally proposed to obtain more information on the roles of organisms in removing radionuclides from the water.

5.3 RELATIONSHIP OF LITERATURE TO RADIONUCLIDES USED IN THE MICROCOSM STUDY

Although bioturbation was observed in the littoral microcosm sediment cores as an area of distinctly different particle size and texture, this mixing apparently had little or no effect on the sediment concentration or activity of radionuclides with increasing depth. Had bioturbation been a significant factor in the redistribution of radionuclides in the sediment surface fraction (0-3 cm), a much more uniform distribution of radionuclides would have been observed in the experimental microcosms compared to the control microcosms. This lack of

bioturbation effects in the littoral microcosms was probably due to the low density of conveyor-belt deposit feeders (mainly oligochaete worms) in the microcosms. The laboratory microcosms used by Fisher et al. (1980) to demonstrate the effect of bioturbation on redistribution of sediment-bound radionuclides had population densities in the order of 100,000 worms/m^2. The worm population densities in the littoral microcosms in this study were much lower than that density.

531 URANIUM

Of the five radionuclides used in the microcosm studies, more uranium remained dissolved in the water than any of the other radionuclides. This increased solubility may permit more rapid dispersion in the sediments (through diffusion in the pore water) and a more rapid release back into the water (remobilization) as a result of the activities of epibenthic and benthic organisms. The highest concentration of uranium in any microcosm component occurred in the limnetic suspended material (average 1927 ug/g). However, this concentration was not transferred effectively to the bottom of the microcosm (i.e. to the sediment in a real world situation). The particulate sedimentary material had a uranium concentration much lower (average 33.7 ug/g) than the suspended material from which it was derived. Within the microcosms having sediments (i.e. profundal and littoral), uranium was concentrated in that component (relative to the initial water concentration) to a small degree (i.e. 4X and 5X).

The mobility of uranium, in a situation of significant bioturbation, should allow for the uniform distribution of this radionuclide from the sediment surface to the depth of maximum feeding.

532 RADIUM-226

Radium-226 is known to be actively concentrated by algae, especially periphytic growth. This was demonstrated in the littoral and limnetic microcosms where these components concentrated radium-226 by factors of 2,300X and 4,000X, respectively. In the limnetic microcosms radium-226 was effectively transferred to the bottom (the sediment in a real world situation) and bound to the organic detritus. In the limnetic microcosms, this particulate sedimentary material exhibited an average activity of 403 Bq/g and was 11,000 times the initial water activity. Because of the affinity of radium-226 for organic substances, the deposition of this material in the sediments either directly through the settling of particulate material or indirectly through sediment focussing from the littoral zone is assured. If the radium-226 associated organics are deposited as a discrete layer they would likely exhibit the same properties as other sediment-bound radionuclides in an actively bioturbated sediment. That is, downward movement within the sediment profile until the zone of active feeding is reached. At this point, the radium-226 is transported to the sediment surface and a general dispersion and mixing within the active sediment layer begins. The close association of radium-226 with organic substances does have the potential of leading to the remobilization of this radionuclide when the organics are broken down by either the fauna or microbiota of the active sediment layer for energy sources.

533 THORIUM-228

Laboratory studies (Onishi et al. 1981) have shown that thorium (and its various isotopes) tends to be removed from water by precipitation as thorium hydroxide and hydrated thorium oxide. Marine microcosm studies (Santschi et al. 1983) demonstrated the removal of thorium by adsorption onto non-living suspended particles. The strong sequesterization of thorium by surface adsorption is likely to produce the same

6.1 INTRODUCTION

Laboratory microcosms designed to simulate limnetic, profundal, and littoral communities were constructed to determine the effects of these communities on the transfer of radionuclides from the water to the sediment. Each set of experimental microcosms had a corresponding control microcosm which was devoid of organisms. After the various biological communities (i.e. limnetic, profundal and littoral) had developed within the microcosms, defined quantities of soluble uranium, radium-226, thorium-228, lead-210 and polonium-210 were introduced into the water of each experimental and control microcosm. After three months, the various components (i.e. water, sediment, macrophytes, etc.) of each microcosm (including the controls) were sampled and the samples analyzed for the five introduced radionuclides.

6.2 LIMNETIC MICROCOSMS

The experimental limnetic microcosms consisted of four components:

- water;
- particulate sedimentary matter (organic material from the planktonic community which settled to the bottom);
- suspended material (planktonic algae and zooplankton); and
- attached algae (algae which colonized the microcosm walls during the three months of the experiment).

The control microcosm contained only filtered (0.45 u) water.

Radionuclide analysis of the limnetic water demonstrated large decreases of radium-226, thorium-228, lead-210 and polonium-210 in both the control and experimental microcosms. However, using a level of significance of 0.05, Student's t-test failed to demonstrate any statistically significant differences between the concentrations of radionuclides in the water of the control and experimental microcosms. Although the percent of uranium which remained in the water was greater than the other radionuclides (relative to the amounts or activities introduced), a significant difference was observed between the water concentrations of only uranium in the control and experimental microcosms. Thus, it appears that the presence of a planktonic community only had a definite effect on increasing the removal of uranium from water.

Analysis of the radionuclide content of the particulate sedimentary matter revealed that the activities of radium-226, thorium-228, lead-210 and polonium-210 were many times the activity introduced into the water. The concentrated activities of these radionuclides associated with the particulate sedimentary matter suggested that over a time frame longer than three months, a substantial transfer of these radionuclides to the sediment might reasonably occur.

The large decrease in the activities of radium-226, thorium-228, lead-210 and polonium-210 in the water of the experimental microcosms was due, in part, to factors other than the presence of the limnetic community. Chief among these was the adsorption of radionuclides to the walls of the microcosm. If the activity lost to the walls of the control microcosm was an indication of the activity lost in the same manner in the experimental microcosms, then the following percentages of activities in the experimental microcosms can be attributed to that factor:

- Radium-226: 31%;
- Thorium-228: 57%;
- Lead-210: 23%; and

o Polonium: 24%.

The suspended material exhibited concentrations of uranium and activities of the remaining radionuclides several hundred to several thousand times the initial concentration or activity added to the water. The increased activities in this component in individual microcosms showed good correlations with the corresponding weight of suspended material, suggesting surface adsorption as being a major factor in this relationship. The concentration of uranium in the attached algal growth was almost identical to the initial water concentration. The activities of radium-226 and lead-210, however, were several thousand times the initial water activity in the attached algal growth.

Among the radionuclides analyzed in the experimental limnetic microcosms, radium-226, thorium-228, lead-210 and polonium-210 attained their highest concentrations in the particulate sedimentary matter. The suspended material exhibited the highest uranium concentration of any microcosm component. This may have been due to the availability of uranium in the water, the active uptake by living algal cells and its subsequent release by dead or senescent cells.

Calculations of mass balances of the radionuclides in the limnetic microcosms showed an average 96% recovery of the added uranium. Lead-210 and radium-226 activities were over-estimated by 23% and 57% respectively. On average, only 57% and 55% of the polonium-210 and thorium-228 activites, respectively, were recovered from the limnetic microcosms.

6.3 PROFUNDAL MICROCOSMS

The experimental profundal microcosms consisted of three components:

- o filtered (0.45 u) water;
- o sediment; and
- o fauna.

The control microcosm consisted of three components:

- o filtered (0.45 u) water; and
- o sterilized sediment.

Radionuclide analysis of the control and experimental profundal microcosm water demonstrated decreases of all radionuclides in the water. However, statistically significant differences (at the 0.05 level) between the control and experimental microcosms were not found for either the water or sediment components. More uranium remained in the water component (relative to the amount added) than any other radionuclide. With the exception of uranium, the sediment became the repository for most of the radionuclides introduced into the water of the profundal microcosms. Interpretation of some of the profundal results was made difficult by the much greater suspended material concentration (resulting from sediment resuspension) in the control microcosm.

With the exception of uranium, greater than 97% of the activities of radium-226, thorium-228, lead-210 and polonium-210 were removed from the water of both the control and experimental microcosms. If adsorption to the microcosm walls is correctly assessed by the leachate component then only between 2% and 3% of the radium-226, thorium-228, and polonium-210 recovered in the profundal microcosms can be accounted for by this component. Other factors are likely to have had a substantial influence in removing the radionuclides from the water.

Within individual microcosm components, radionuclides exhibited different distributions and concentrations. The sediment concentrated the radionuclides by factors varying from 4 (uranium) to 13x (polonium-210). By contrast, the suspended material contained between 35 (radium-

226) to 860 (polonium-210) times the initial water concentration or activity. Although the fauna of the experimental microcosms concentrated all the radionuclides, polonium-210 was concentrated to a much greater extent (i.e. 525 times the initial water concentration) than the other radionuclides.

Among individual radionuclides, uranium, thorium-228, and polonium-210 reached their highest concentrations or activities in association with the suspended material. Radium-226 and lead-210 attained their highest activities associated with the experimental microcosm fauna.

Inverse relationships were observed for both uranium concentrations and thorium activities associated with their respective microcosm fauna dry weights. As well, an inverse relationship was observed between polonium-210 activity and the respective dry weights of suspended material. Although only three data points were available for these correlations (all with coefficients greater than 0.8) the meaning of these relationships is not clear.

The mass balances attempted for the profundal microcosms were poor, as less than 54% of the radionuclides introduced into the microcosms could be accounted for in the summation of microcosm components.

6.4 LITTORAL MICROCOSMS

The experimental littoral microcosms consisted of eight components:

- o water;
- o suspended material;
- o fauna;

- o macrophytes;
- o periphyton;
- o macrophyte detritus (macrophytes which died during the experimental period);
- o 0-3 cm sediment (surface fraction); and
- o 3-B cm sediment (3 cm to microcosm bottom or deep fraction).

The control littoral microcosm consisted of four components:

- o water;
- o 0-3 cm sediment (surface fraction);
- o 3-B cm sediment (deep fraction); and
- o periphyton.

Although the control microcosm was devoid of life (i.e. sterile sediment and 0.45 u filtered water) a small amount of periphyton had developed at the glass-water surface interface at the end of three months.

Radionuclide analysis of the littoral water demonstrated large decreases of radium-226, thorium-228, lead-210 and polonium-210 in both the control and experimental microcosms. However, statistically significant differences between the activities of these radionuclides in the control and experimental microcosms (at the 0.05 level) could not be demonstrated. Although the percent of uranium which remained in the water of the littoral microcosms was much greater (relative to the amount introduced) than the other radionuclides, a significant difference between the control microcosm water and the lower range of uranium concentrations in the experimental microcosms was observed for this element.

This difference was complemented by a significant increase in the uranium concentration of the surface sediment of the experimental microcosms compared to the control. Thus, it appeared that the littoral

community had a significant effect on the transfer of uranium from the water to the sediment.

The large decreases in activity (i.e. greater than 93%) observed for the other radionuclides in the experimental microcosms must have been due to factors other than the presence of a littoral community. These could have included precipitation from the water as inorganic complexes or absorbed onto fine particulate resuspended sediment. No leachate of the control littoral microcosm was obtained. At the time the radionuclides were introduced into the microcosms, the experimental microcosm walls were completely covered with periphyton whereas the control microcosm was devoid of such growth. Under these conditions it was felt that loss of radionuclides from the water to microcosm walls would be insignificant compared to the uptake by the periphyton.

The surface sediments (0-3 cm) of the experimental microcosms had approximately 10 times the initial water activities of radium-226, thorium-228, lead-210 and polonium-210.

Within the individual biological microcosm components, periphyton, macrophytes and suspended material exhibited higher activities of radium-226 than any other radionuclide. The fauna was associated with a high activity of polonium-210 while the macrophyte detritus had a high concentration of uranium.

Among radionuclides, radium-226, thorium-228 and lead-210 exhibited their highest activities in association with the periphyton component. Polonium-210 exhibited its highest activity in the fauna and uranium its highest concentration in the macrophyte detritus.

Both uranium concentrations and radium-226 activities were found to be inversely correlated with their respective weights of suspended material. Uranium concentrations were also found to be posi-

tively correlated with periphyton dry weight and radium-226 activities were negatively correlated with the same parameter. Although the regression coefficients were greater than 0.845 in both cases, an adequate explanation for these relationships could not be found.

The inverse relationship observed between fauna dry weights and their associated polonium-210 activities (correlation coefficient 0.993) might be explained by a positive discrimination for this radionuclide by the littoral fauna. This same discrimination for polonium-210 has been previously observed for marine fauna, specifically molluscs.

Mass balances for the littoral microcosms demonstrated an average recovery of 66% of the uranium and 90% of the thorium-228 initially added. Summation of the average microcosm activities for radium-226 accounted for 90% of the initial activity initially added. Summation of the average microcosm activities for lead-210 and polonium-210 resulted in a 4% and 22% over-estimation, respectively, of the initial activity added.

6.5 BENTHIC BIOTURBATION MICROCOSMS

A literature review conducted by Monenco Consultants Limited (1985) demonstrated that sophisticated laboratory microcosms had been extensively used to study the redistribution of sediment adsorbed radionuclides within an actively bioturbated surface sediment. Although the radionuclides used in these studies were not the radionuclides of concern to the National Uranium Tailings Program (i.e. uranium, radium-226, thorium-228, lead-210 and polonium-210), the results of these studies could be used to adequately describe the fate of the aforementioned radionuclides.

Sediment adsorbed uranium, radium-226, thorium-228, lead-210 and polonium-210, if deposited as a discrete layer on an actively bioturbated sediment surface, would move downward at a fixed rate until it reached the zone of maximum feeding by the vertically oriented, deposit feeding macrobenthos. As sediment bioturbation continues, the discrete layer of radionuclide associated sediment is mixed throughout the active sediment layer. The rate at which this mixing occurs would depend on the population density of the vertically oriented, deposit feeding macrobenthos, the species composition, temperature, sediment type, dissolved oxygen and interactions with other organisms.

In relation to the radionuclides of concern to the National Uranium Tailing Program, uranium would probably disperse through the active sediment layer much faster than the other radionuclides due to its greater solubility in water and its subsequent diffusion within the active sediment layer pore water.

While deposition of organically bound radium-226 might present a situation similar to that of other sediment-bound radionuclides, the microflora of an actively bioturbated sediment has the potential to release radium-226 back into the water.

Both thorium-228 and lead-210 are strongly adsorbed to sediment particulate material and as such would become mixed within the actively bioturbated sediment surface. Polonium-210 likewise has the potential to be mixed within the active sediment in the same manner as thorium-228 and lead-210. However, Monenco's littoral microcosms demonstrated a discrimination for polonium-210 by the fauna, especially the snails or molluscs. Thus, substantial quantities of polonium-210 may be taken up by the epibenthic organisms, such as snails, and not mixed effectively in the sediment.

The rate at which the sediment-bound radionuclides are buried (i.e. passed below the zone of active feeding) is a function of the sedi-

mentation rate. Low sedimentation rates would allow a continual mixing of the sediment-bound radionuclides. High sedimentation rates would allow dilution of the active sediment layer and a more rapid rise of that layer, leaving behind (below the zone of active feeding) sediment-bound radionuclides in much larger quantities.

6.6 SUMMARY

In general, the microcosm studies demonstrated that the organisms in the limnetic and littoral communities can have a major effect in the transport of uranium from the water to the sediment. The high radionuclide activities associated with the settled particulate material in the limnetic microcosms suggest that a substantial amount of radionuclide activity in water can be transported to the sediment by the presence of a well developed planktonic community. However, judging from the results of the limnetic microcosms, the period of time required for this transfer is longer than three months.

The profundal community (chiefly benthic fauna) appears to influence the transfer of radionuclides from the water to the sediment. However, this transfer was not well defined by the microcosm experiment.

The high activities of radium-226, thorium-228, lead-210, and polonium-210 in the littoral microcosm periphyton (relative to the other components) demonstrate the importance of this littoral component in the removal of radionuclides from water.

Further studies concerning the effect of lacustrine communities on the removal of radionuclides from the water and transfer to the sediment should investigate the various relationships between radionuclide concentration or activity and the biomass of community components as observed in this study. Specifically, the inverse

relationship observed between the littoral macroinvertebrate fauna and polonium-210 activity should be studied further. Specifically, the potential for significant bioaccumulation of polonium-210 by freshwater snails (inferred from the littoral microcosm study) should be investigated. The littoral zone is used a nursery area for some fish species and supplies food for several species of birds. Thus, a potential exists for the transfer of polonium-210 to vertebrate species.

The use of large enclosures in natural lakes (i.e. limnocorrals) during the open water season would make possible in-situ studies of the removal of radionuclides from introduced tailings water. These in-situ studies could also be used to determine management strategies for lakes impacted by uranium mining. Such potential strategies could include:

- fertilization of the resident limnetic community for increased uptake and transport of radionuclides to the sediment;
- the use of selective biocides to eliminate the vertically oriented deposit feeding macrobenthos to allow the undisturbed burial of radionuclides adsorbed to settled particulate material; and
- the use of specific inorganic materials for the adsorption and removal of radionuclides from the water.

PART 7

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PART 8

GLOSSARY OF TERMS

8.0 GLOSSARY OF TERMS

Lacustrine - of, relating to, or growing in lakes.

Limnetic Zone - the open-water zone of a lake to the depth of effective light penetration. In general, this depth will coincide with the level at which the surface full sunlight intensity is reduced to about one percent. The analagous term used in oceanography is pelagic.

Profundal Zone - the bottom and deep water area which is beyond the depth of effective light penetration (i.e. less than one percent of surface full sunlight intensity).

Littoral Zone - the shallow-water interface zone between the land and limnetic zone with light penetration to the bottom; typically occupied by rooted plants in natural ponds and lakes.

Periphyton - although originally used to designate microfloral growth (chiefly phototropic) on plants, the term is now generally used to refer to microfloral growth upon any substrate. Within the context of this report, periphyton is used to designate the microfloral growth on aquatic plants and the walls of the littoral microcosms.

Attached Algae - literally, the algae attached to a surface and generally synonymous with "periphyton". In the context of this study, the term attached algae is used to refer to the algal growth on the walls of the limnetic microcosm which developed over a period of three months. The term "periphyton" was not used, as periphyton is not a normal component of the limnetic zone.

Suspended Material - the material (organic or inorganic) suspended in the water by means of turbulence or through the buoyancy or swimming

abilities of living organisms. Within the context of this study, the suspended material consisted chiefly of phytoplankton (limnetic and littoral microcosms) and resuspended sediment (profundal microcosms).

Particulate Sedimentary Matter - in the context of this study, the material which settled to the bottom of the limnetic microcosms as a result of growth and death of organisms in the planktonic community (in limnetic microcosms) suspended in the water column.

Macrophyte - the term applied collectively to the aquatic vascular plants and macroalgae which developed in the littoral microcosms in this study.

Macrophyte Detritus - in this study, the portions of the aquatic macrophytes, chiefly leaves and stems, which died during the three month experimental period and were in the process of decomposing at the time microcosm component samples were collected for radionuclide analysis.

Microcosm Study - an attempt to bring an intact, minimally disturbed, piece of an ecosystem into the laboratory for study in its natural state. As used in this study, a simulation of specific lacustrine communities (i.e. limnetic, profundal and littoral) for the study of the removal of radionuclides from water by biological organisms.

APPENDIX A

PHYTOPLANKTON CELL DENSITIES IN LIMNETIC MICROCOSMS

The phytoplankton cell desities in the limnetic microcosms sampled at two week intervals are presented in Table A-1. As stated in the text of this report, the natural lake water placed in the experimental microcosms had to be maintained for several weeks and stimulated by the addition of inorganic nutrients before a sufficiently dense phytoplankton population was produced. The following is a cursory review of the type of phytoplankton contained in the microcosms at the time of collection.

5 May 1985

Microcosms 1 and 2: Population composed mainly of Ulothrix and Monoraphidium (Chlorophyta and Bacillariophyta, respectively).

Microcosms 3 and 4: Populations composed mainly of diatoms (Bacillariophyta).

19 May 1985

Microcosms 1, 2, 3 and 4: Populations composed mainly of diatoms (Bacillariophyta).

2 June 1985

Microcosms 1, 2, 3 and 4: Monoraphidium (Bacillariophyta) dominant with some filamentaous and unicellular chloraphyta.

16 June 1985

Microcosms 1, 2, 3 and 4: Unicellular Cryptophyta and Chlorophyta dominant.

TABLE A-1

Phytoplankton Cell Densities in Limnetic Microcosms

Sample Date	Microcosm	Density (cells/ml)
5 May 1985	1	5984
	2	20274
	3	27141
	4	131781
19 May 1985	1	164
	2	352
	3	474
	4	540
2 June 1985	1	17331
	2	13734
	3	13047
	4	4480
16 June 1985	1	17004
	2	7586
	3	8993
	4	4529
30 June 1985	1	10628
	2	29437
	3	75878
	4	45873
14 July 1985	1	2796
	2	10137
	3	1439
	4	4578

30 June 1985

Microcosms 1, 2, 3 and 4: Populations dominated by a number of different Bacillariophyta (i.e. diatom) genera. Also present were unicellular species of Cryptophyta and Chlorophyta.

14 July 1985

Microcosm 1: Population dominated by Bacillariophyta and also including small solitary Chlorophyta.

Microcosms 2, 3 and 4: Populations as in microcosm I, but also including a filamentous blue-green alga.